thesis proposal:

building integrated wind power generation

faculty advisor:

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21 december 2007

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executive summary

Granby Tower is a proposed mixed-use, luxury, high-rise located in the downtown historic district of Norfolk, Virginia. The tower stands 450 feet to the top of its spire, and consists of 34 floors, 6 of which are reserved for parking. Post-tensioned slabs allow for maximum span to depth ratio, while dual shear wall cores are centrally located to allow for unobstructed views of downtown Norfolk.

depth study

Research will be conducted to investigate the possibility of integrating wind power generation into the design of Granby Tower, as a means of capitalizing on the favorable wind speeds. Granby Tower will be the tallest building in Norfolk, so there will be little building interference affecting the wind available for power generation. By funneling wind through the building's interior, the effective story shears decrease on the windward face and the leeward suction decreases due to Bernoulli's Principal. A dynamic analysis will be required to determine the resulting lateral loads, but an expected decrease in loads offers the potential to design a more efficient shear wall system. Some slight changes in shear wall orientation and location may need to occur to allow for turbines and additional equipment. The feasibility of this system will be evaluated by cost, energy production, architectural impact, and efficiency in lateral design.

breadth studies

Sustainability

The first breadth study will focus on receiving certification through the United States Green Building Council's Leadership in Energy and Environmental Design (LEED) program. LEED is a rating system that incorporates proper planning, material selection, and commissioning to minimize the impact of a building on its environment. Incorporating renewable energy generation into the building process has potential to earn at least 6 points: Energy & Atmosphere, Credit 2 – On-Site Renewable Energy, Energy and Atmosphere, Credit 6 – Green Power, and Innovation in Design, Credit 1.1-1.4 – Innovation in Design. Through multiple other green measures, this breadth study will demonstrate that luxury can be "green."

Architecture

Allowing for wind tunnels at various locations will drastically affect the architecture of Granby Tower. Floor plans on and around the levels chosen for wind tunnels and power generation require alterations to account for reduction of floor space, changes in shear wall layout, and possible changes in floor height. Consideration for exterior alterations due to location of wind tunnels and funneling of wind into said tunnels is necessary. Wind studies will determine if building rotation is required to maximize efficiency, in which case lobby space and store front conditions should be altered.

introduction

The Granby Tower (*fig 1*) is a proposed mixed-use, luxury, high rise located in the downtown historic district of Norfolk, Virginia. Historically Granby Street was the premier shopping, dining, gathering and theatre corridor, and these luxuries were supplemented by the direct connection to the Elizabeth River waterfront. The conveniences of Granby Street fell out of favor in the 1960's as suburban development between Norfolk and Virginia Beach promised bargain shopping malls. Due to the decline in popularity of a very important landmark and cultural center, city officials began reviving the city center in the 1970's and are still working to regain the prestige that Granby Street held in the early 1900's.

Granby Tower will be the tallest building in Norfolk upon completion and will provide roughly 300 luxury apartments with views of downtown Norfolk and the Elizabeth River, 6 stories of parking, a roof top fitness center and pool, leasable office space. It is becoming increasingly popular in the Norfolk and Virginia Beach areas to build above parking structures for a number of reasons. One of the most obvious reasons is that you must provide parking space, and since the site has little open space for a free standing garage, the best way to maximize your profit is to utilize the lower floors for parking. The second main reason for an above ground parking structure housed within the buildings structure is due to the sandy soil conditions and high ground water table that don't allow for deep foundations. Most designs, especially heavy concrete structures, require slab on grade with deep piles to penetrate the deep Yorktown Strata layer that is buried beneath layers of unstable sand and clay.

The lateral force resisting system at Granby Tower is designed as a concrete shear wall core which helps to maximize leasable space while keeping most views unobstructed. The floor framing system is a two-way flat-plate post-tensioned slab with minimal drop panels to capitalize on floor to ceiling height. The longest span seen by the slab is 30 feet with typical bays at 26' x 30'. These design features will allow spaces to feel spacious and elegant and with a design focused on luxury, it is easy to see that Granby Tower will stand as a landmark for the city to celebrate a vibrant history and a promising future.

fig 1 – rendering of Granby Tower

structural overview

foundation

To determine the soil bearing capacity, sixteen (16) 100 to 110-foot deep Standard Penetration Test borings were drilled within the proposed Granby Tower site. Borings were conducted in accordance with ASTM D 1586 standards and performed with rotary wash drilling procedures to analyze the soil types at 5 foot integrals. Soil tests determined that the first 20 feet of most samples consisted of silty fine sand (SM) or poorly graded fine sand (SP-SM). The next 25 feet of bore was composed of clay (CL) followed by 55 feet of poorly graded fine to coarse sand (SP-SM) and/or silty fine sand (SM). Due to the composition of the soil and location of the groundwater table (6 to 7 feet below grade), the geotechnical engineer recommended a deep pile foundation system with driven, precast, pre-stressed, concrete piles since shallow foundations would result in excessive settlements due to the extreme building weight.

To determine the feasibility and required depths of the piles, fifteen test piles were driven with and evaluated with a Pile Driving Analyzer. The analysis dictated the use of 12" square, precast, pre-stressed concrete piles (SPPC) at 80 feet deep with 100 ton capacity and 14" SPPC at 90 feet with 140 ton capacity. Roughly 1000 piles were driven throughout the site with 255-14" SPPC piles supporting the ordinary shear wall core (*fig 2*). Due to the lateral forces seen by the shear walls, the outer 156 piles are designed for tension. The pile cap supporting the shear wall is 10 feet thick with a 28-day compressive strength (f'c) of 5000 psi and #10 and #11 reinforcing on top and bottom, while all other pile caps will be designed with an f'c of 4000 psi and # 7 and #8 reinforcing.

The slab on grade is 5" thick, reinforced with 6x6-W2.9xW2.9 welded wire fabric over a 10 mil polyethylene vapor barrier. The geotechnical engineer specified the slab to be placed over 4" porous fill with less than 5% passing the No. 200 sieve to act as a capillary barrier. The slab should also be "floating" in the sense that it is not rigidly connected to columns or foundations to reduce cracking.

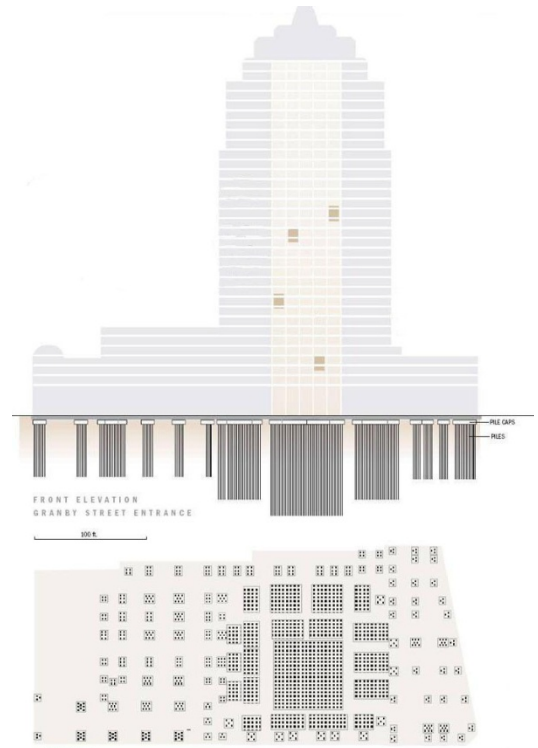

fig 2 – front elevation and plan of piles for Granby Tower. source: Abiouness, Cross and Bradshaw, Inc.

floor system

The floor system for the Granby Tower consists of a two-way flat plate post tensioned slab (*fig 3*) designed in accordance with the Post-Tensioning Manual 6th Edition by the Post-Tensioning Institute and ACI 318-02. All slabs are designed with a 28-day compressive strength (f'c) of 5000 psi, and the first 7 levels of the tower require a 9" slab while the remaining levels are designed as an 8" slab. Tendons for post-tensioning will be ½" diameter (ø), 7-wire, low relaxation strand, fully encased in grease with a minimum sheathing thickness of 50mm. Maximum sag for tendons will be 5 ½" and supported by chairs or bolsters. Post-tensioning will occur when the concrete has reached 75% of its designed f'c, and all of the uniform tendons shall be stressed before banded tendons. Uniform tendons are even distributed through the north-south (long) direction with a maximum span of 26’ while banded tendons run east-west (short direction) along column lines with a maximum span of 30’.

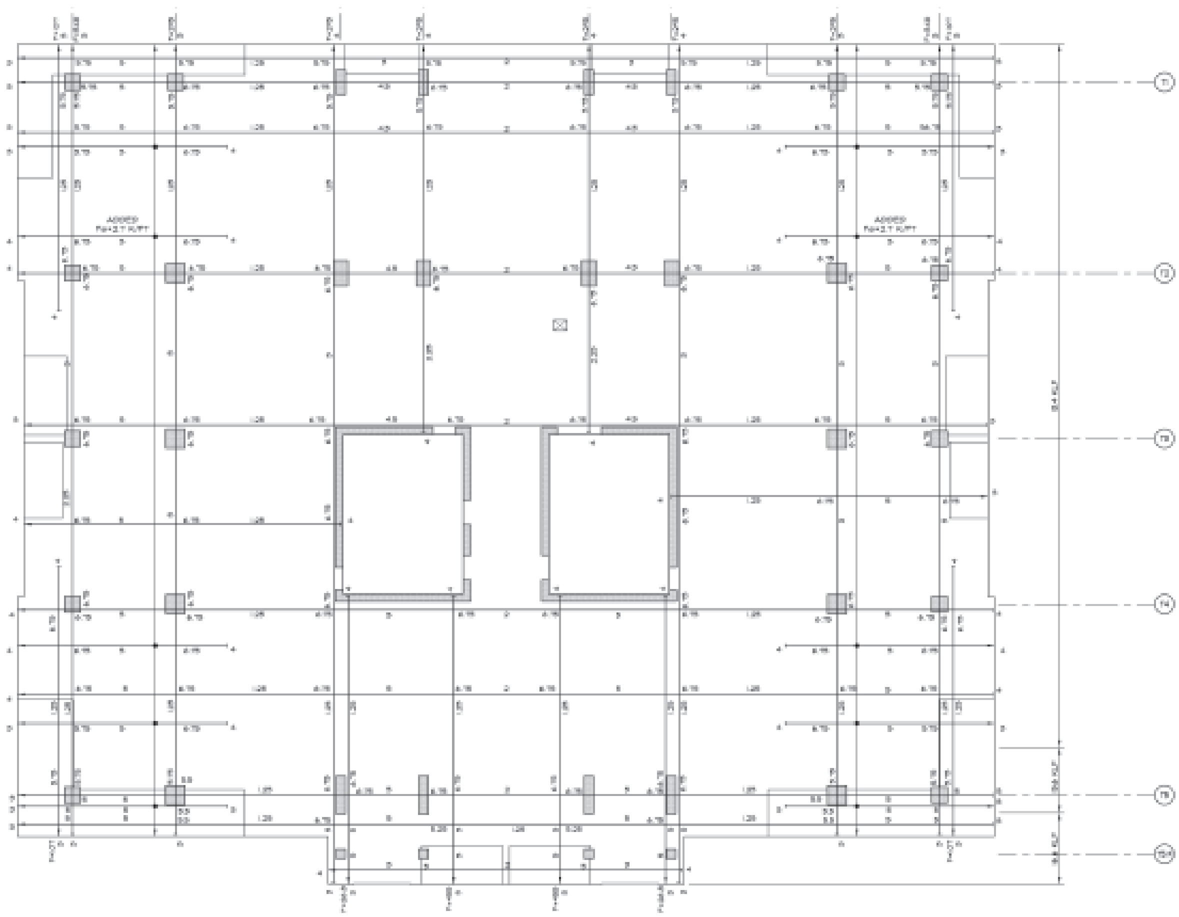

fig 3 – typical post-tensioning plan for levels 8 through 12. Plan and True North **→N (x-direction)**

columns

Gravity columns are laid out on a fairly regular grid with the largest bay at 26’x30’ (refer again to *fig 3* for column layout). Roughly 32 columns run the full building height with some of the exterior columns terminating at the buildings first significant set-back on the 29th floor. Most columns are square reinforced columns with rebar ranging from #7 to #10, but rectangular columns with the strong axis in the short building direction (east-west) are architecturally situated in central east and west apartments. Columns above the parking garage (Level 7) are designed with f’c = 5000 psi, and columns between Level 6 and the foundation are designed with f’c = 6500 psi. Banded tendons running through columns should be within 1.5 x T (thickness slab) of the column face and placed above other uniform tendons or rebar. Some drop panels are required on upper floors as column sizes decrease and slab edges become flush with exterior columns.

lateral system

The lateral load resisting system of Granby Tower consists of ordinary reinforced concrete shear walls (*fig 4*) that were designed in accordance to ACI 318-02. These two shear wall cores house the elevators, stairs, electrical and gas lines, and fire dampers. The first 6 levels consist of 24" thick reinforced shear walls with f'c = 8000 psi, while the remaining levels consist of 14" shear walls with 28-day compressive strengths of 6000 (Levels 7 through 23) and 5000 psi (Levels 24 through 34). Typical vertical reinforcement ranges in size and spacing from #10 @ 6" o.c. to #8 @ 12" o.c. while horizontal reinforcement ranges from #6 @ 6" o.c. to #5 @ 12" o.c. Typical end reinforcement consists of ten vertical rebar within a square section determined by the wall width and #4 ties @ 8" o.c vertical spacing from the foundation to Level 7 and #3 ties @ 8" o.c. vertical spacing from Level 7 to 34.

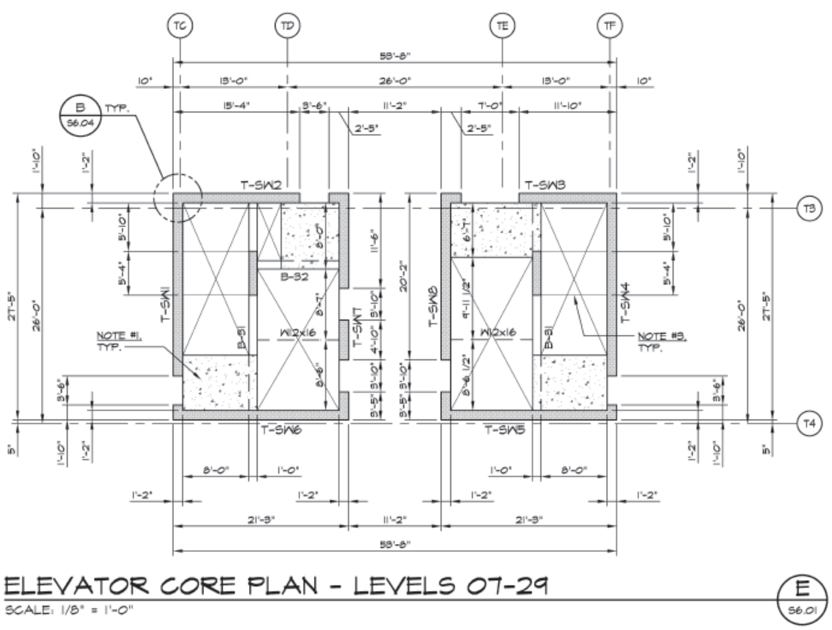

fig 4 – typical plan of shear wall core.

proposal

problem statement

Granby Tower is a beautifully designed luxury tower in downtown Norfolk, Virginia that reinstates the historic prestige of Granby Street, but there is minimal integration of the surrounding resources or indication of the current trends encouraging sustainable building integrated solutions. Since the country is beginning to address the imminent energy crisis, alternative means of power generation are becoming increasingly popular. The idea of incorporating a means of supplemental power generation is progressive, but current outlook suggests that the value of such systems is increased by expected future energy costs.

proposed solution

Research will be conducted to investigate the possibility of integrating wind power generation into the design of Granby Tower, as a means of capitalizing on the favorable wind speeds. Granby Tower will be the tallest building in Norfolk, so there will be little building interference affecting the wind available for power generation. By funneling wind through the building's interior, the effective story shears decrease on the windward face and the leeward suction decreases due to Bernoulli's Principal. A dynamic analysis will be required to determine the resulting lateral loads, but an expected decrease in loads offers the potential to design a more efficient shear wall system. Some slight changes in shear wall orientation and location may need to occur to allow for turbines and additional equipment. The feasibility of this system will be evaluated by cost, energy production, architectural impact, and efficiency in lateral design.

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methods

depth

A concise dynamic analysis will be conducted to understand how the building reacts to the new wind conditions. Due to the complexity of this task, assistance from some industry professionals with design experience in this field may be necessary. I have contacted some experienced designers for information and/or insight, and these contacts will prove invaluable as this thesis research progresses.

The results of the analysis will be formulated into tangible results that can be used for preliminary shear wall design. Redesigned shear wall cores will be modeled in ETABS to verify capacities and efficiency of design. Modeling the new design in ETABS will dictate whether centrally located shear wall cores are the best for resisting the lateral loads.

breadths

Sustainability

Since no considerations were taken to make Granby Tower "green," earning 26 points (enough to qualify for a LEED Certified rating) is definitely possible. The USGBC New Construction & Major Renovation, Version 2.2 Reference Guide will provide the best insight as to which points are possible. With at least 6 points available for the concept of integrating wind power generation into the building plan, this leaves roughly 20 points required to fulfill the rating criteria. Some points worth pursuing in this sustainability breadth include:

SS Credit 4.1 • Alternative Transportation: Public Transportation Access

SS Credit 4.2 • Alternative Transportation: Bicycle Storage & Changing Rooms

SS Credit 7.1 • Heat Island Effect: Non-Roof

WE Credit 1.1 • Water Efficient Landscaping: Reduce by 50%

WE Credit 3.2 • Water Use Reduction: 20% Reduction

EA Credit 3 • Enhanced Commissioning

MR Credit 2.1 • Construction Waste Management: Divert 50% From Disposal

MR Credit 4.1 • Recycled Content: 10% (post-consumer + ½ pre-consumer)

EQ Credit 3.2 • Construction IAQ Management Plan: During Construction

EQ Credit 4.1-4.4 • Low Emitting Materials

EQ Credit 6.2 • Controllability of Systems: Thermal Comfort

EQ Credit 8.1 • Daylight and Views: Daylight 75% of Space.

Architecture

Wind studies will determine the best methods for altering floor plans or building elevations, but preliminary studies suggest that a change in building orientation is required. Wind rose plots provided in appendix a display the distribution of wind speed and direction for Norfolk, Virginia. The most frequent winds occur from north to south (N-S) and southwest to northeast (SW-NE), so the best means of utilizing this wind requires rotating the building at least one cardinal direction (90 degrees). By rotating the building and cores as a unit, the structural design will not be sacrificed, but the Granby Street façade (original east façade) will need ameliorating.

To minimize architectural intrusion while maximizing power generation potential, a tunnel housing non-directional wind turbines will connect opposing windward/leeward facades and run through the existing shear wall cores (*fig 5*). To address the limited space available, turbines produced by Quiet Revolution will be considered (appendix b). The tunnel required to house these turbines will intrude into existing residences on these floor and some leasable space will be sacrificed.

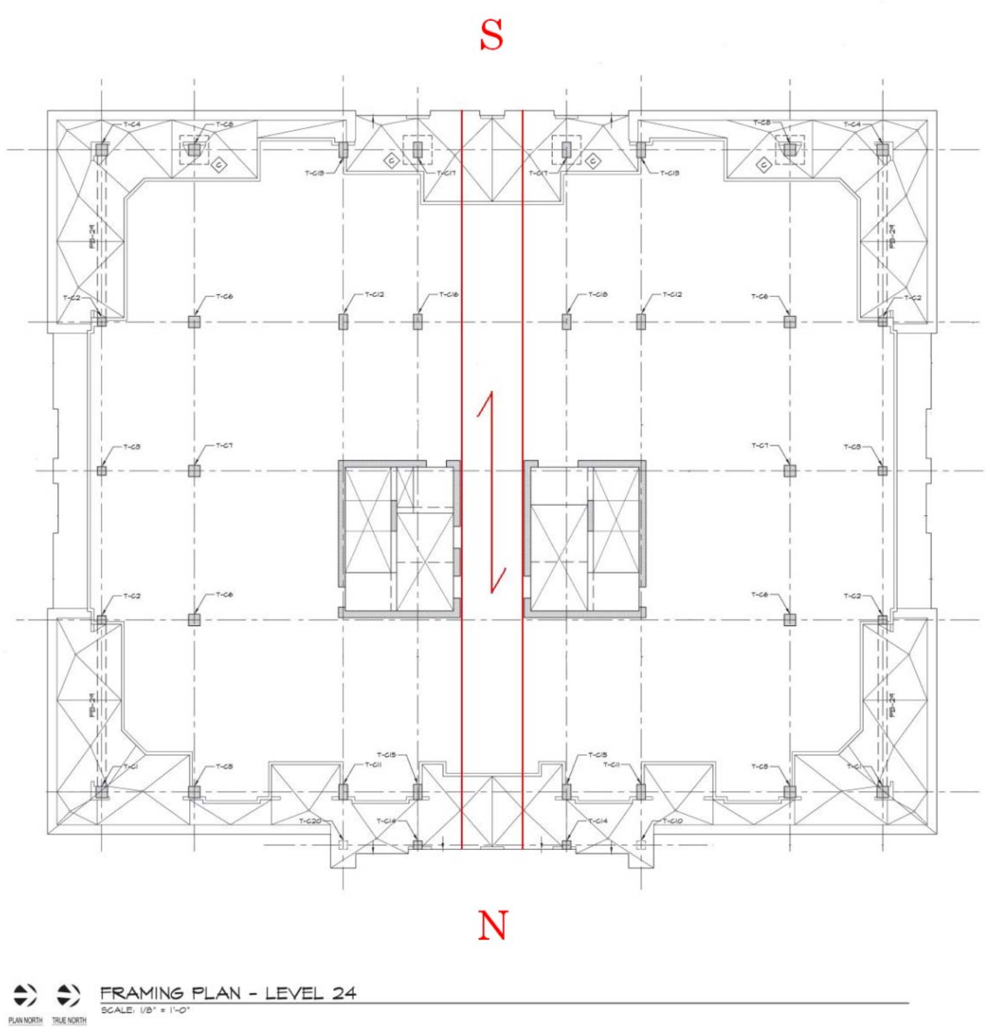


fig 5 – proposed location of tunnel housing wind turbines with new building orientation considered

tasks and tools

depth

Task 1: Determine trial locations for wind openings and possible shear wall modifications.

Task 2: Model building with dynamic analysis program.

- Run several models to understand effect of opening height, size, and locations.
- Determine equivalent lateral loads imposed.
- Discuss results with industry professional.

Task 3: Establish trial shear wall sizes due to new load distribution.

- Consider openings for elevators due to new building plan.

Task 4: Analyze building in ETABS with new lateral loads and shear walls.

- Check shear strength, overturning moment, and drift.
- Spot check new shear walls using ETABS for load distribution.
- Compare new design to existing.

breadths

Sustainability

Task 1: Research possible LEED points.

- Determine requirements necessary to earn credit.
- Investigate means of fulfilling requirements.
- Evaluate feasibility.

Task 2: Document process.

Architecture

Task 1: Design new floor plans.

- Consider shear wall alterations and wind tunnel.

Task 2: Research possible façade design solutions.

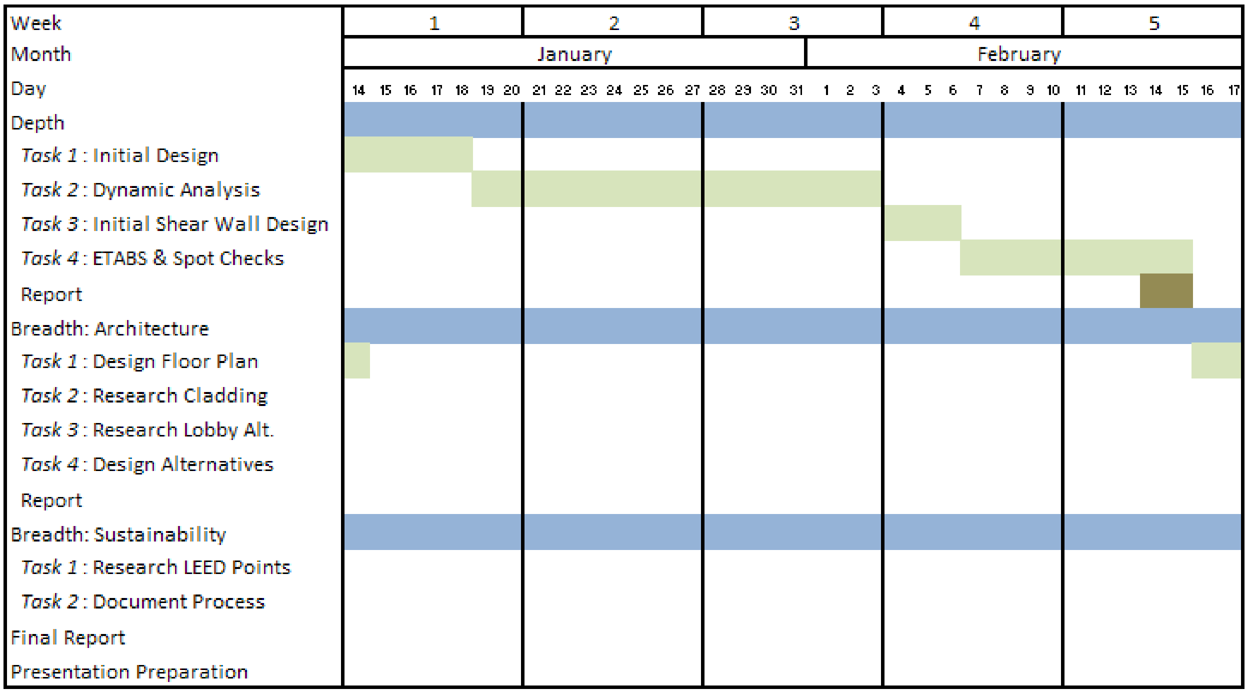
- Investigate building materials at wind openings.

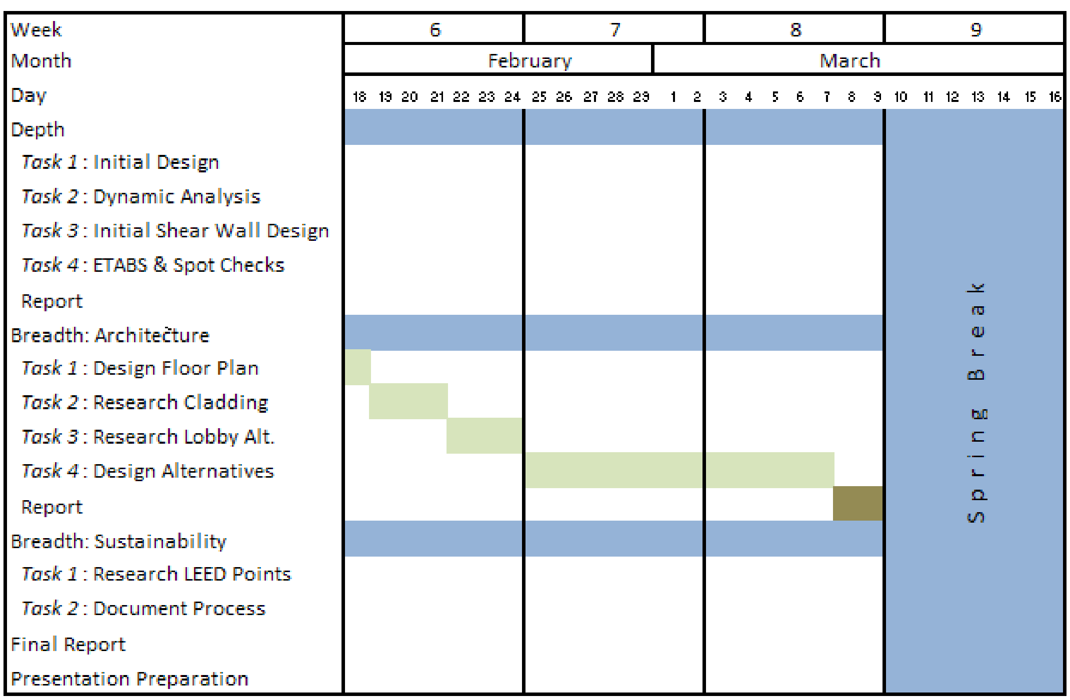
Task 3: Research lobby design alternatives.

- Consider building orientation and shear wall design.

Task 4: Design façade and lobby.

schedule


Week
1
2
3
4
5
Month
January
February
Day
14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
Depth
Task 1 : Initial Design
Task 2 : Dynamic Analysis
Task 3 : Initial Shear Wall Design
Task 4 : ETABS & Spot Checks
Report
Breadth: Architecture
Task 1 : Design Floor Plan
Task 2 : Research Cladding
Task 3 : Research Lobby Alt.
Task 4 : Design Alternatives
Report
Breadth: Sustainability
Task 1 : Research LEED Points
Task 2 : Document Process
Final Report
Presentation Preparation


Week
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8
9
Month
February
March
Day
18 19 20 21 22 23 24 25 26 27 28 29 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Depth
Task 1 : Initial Design
Task 2 : Dynamic Analysis
Task 3 : Initial Shear Wall Design
Task 4 : ETABS & Spot Checks
Report
Breadth: Architecture
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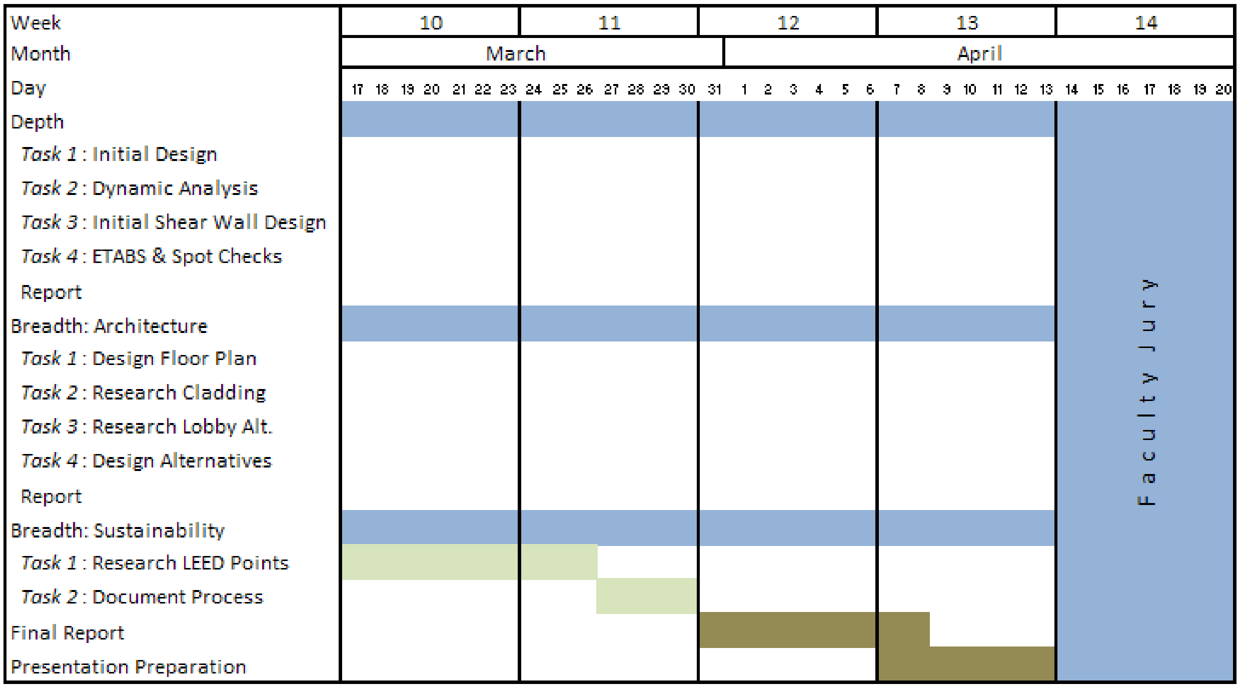
Task 3 : Research Lobby Alt.
Task 4 : Design Alternatives
Report
Breadth: Sustainability
Task 1 : Research LEED Points
Task 2 : Document Process
Final Report
Presentation Preparation
Spring Break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11
12
13
14
Month
March
April
Day
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Depth
Task 1 : Initial Design
Task 2 : Dynamic Analysis
Task 3 : Initial Shear Wall Design
Task 4 : ETABS & Spot Checks
Report
Breadth: Architecture
Task 1 : Design Floor Plan
Task 2 : Research Cladding
Task 3 : Research Lobby Alt.
Task 4 : Design Alternatives
Report
Breadth: Sustainability
Task 1 : Research LEED Points
Task 2 : Document Process
Final Report
Presentation Preparation
Faculty Jury

conclusion

Throughout the upcoming semester, research will be conducted to determine the benefits of building integrated wind power generation on the lateral load resisting system of Granby Tower. Computer modeling will supplement research by providing tangible data for analyzing the efficiency of the proposed revisions to the existing shear wall system. The feasibility of this system will be evaluated by cost, energy production, architectural impact, and efficiency in lateral design.

A breadth study on the effects wind integrated design has on the building's architecture will be conducted. Research will determine the best means of addressing the interface of cladding at the wind tunnel openings, and also how to properly address the condition caused at the lobby from changing the buildings orientation. Redesign of floor plans on and around tunnel openings will occur with special attention to the effects of removing leasable floor space, the change in shear wall design, and possible acoustical issues.

A second breadth study will focus on receiving certification by the United States Green Building Council's Leadership in Energy and Environmental Design Rating System. Research will provide insight as to the best means of fulfilling LEED requirements and the feasibility of implementing design solutions to earn proposed credits. The incorporation of on-site renewable power generation presents the potential to earn at least 6 LEED points, so a minimum of 20 more points are necessary for certification. While Granby Tower is a proposed luxury apartment high-rise, this breadth study will seek to prove that luxury can be sustainable.

appendix a

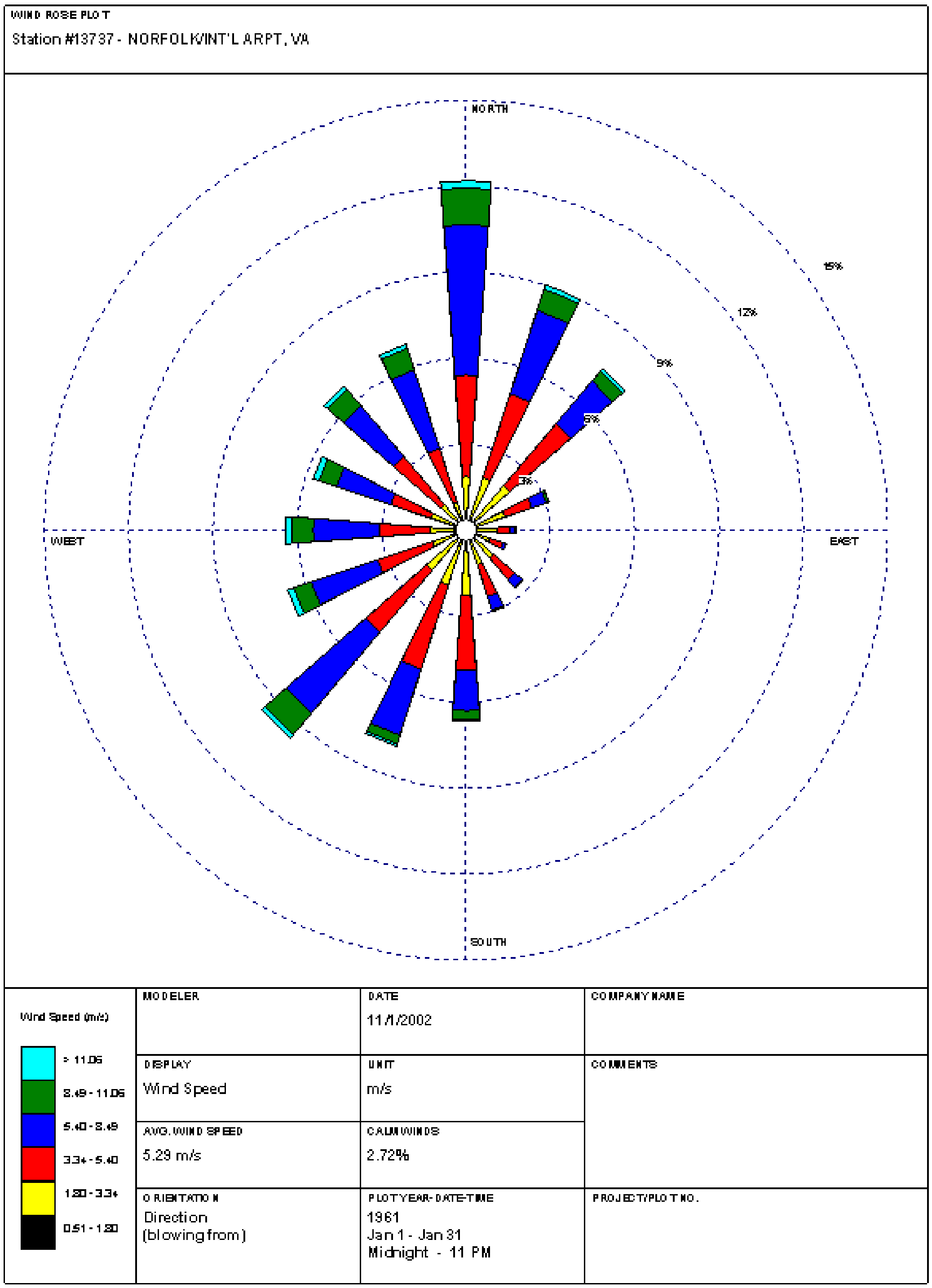
wind roses

The following wind rose plots represent the distribution of wind speed and direction for Norfolk, Virginia. Measurements, recorded at the Norfolk International Airport (Climate Station #13737) by the Solar and Meteorological Surface Observation Network, represent data collected hourly between the years of 1961 and 1990. Wind speeds were measured at 20 feet and 33 feet above ground level from 1961 to 1982 and 1982 to 1996, respectively.

To convert wind speeds from m/sec to mph, multiply by 2.237.

All information provided care of the United States Department of Agriculture Natural Resources Conservation Service. For more information regarding wind roses or weather data, refer to the USDA NCRS National Water and Climate Center website below.

http://www.wcc.nrcs.usda.gov/climate/windrose.html.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Station #13737 - NORFOLK/INT'L ARPT, VA
NORTH
SOUTH
WEST
EAST
3%
6%
9%
12%
15%
Wind Speed (m/s)
> 11.06
8.49 - 11.06
5.40 - 8.49
3.34 - 5.40
1.80 - 3.34
0.51 - 1.80
MODELER
DATE
11/1/2002
COMPANY NAME
DISPLAY
Wind Speed
UNIT
m/s
COMMENTS
AVG. WIND SPEED
5.29 m/s
CALM WINDS
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Direction
(blowing from)
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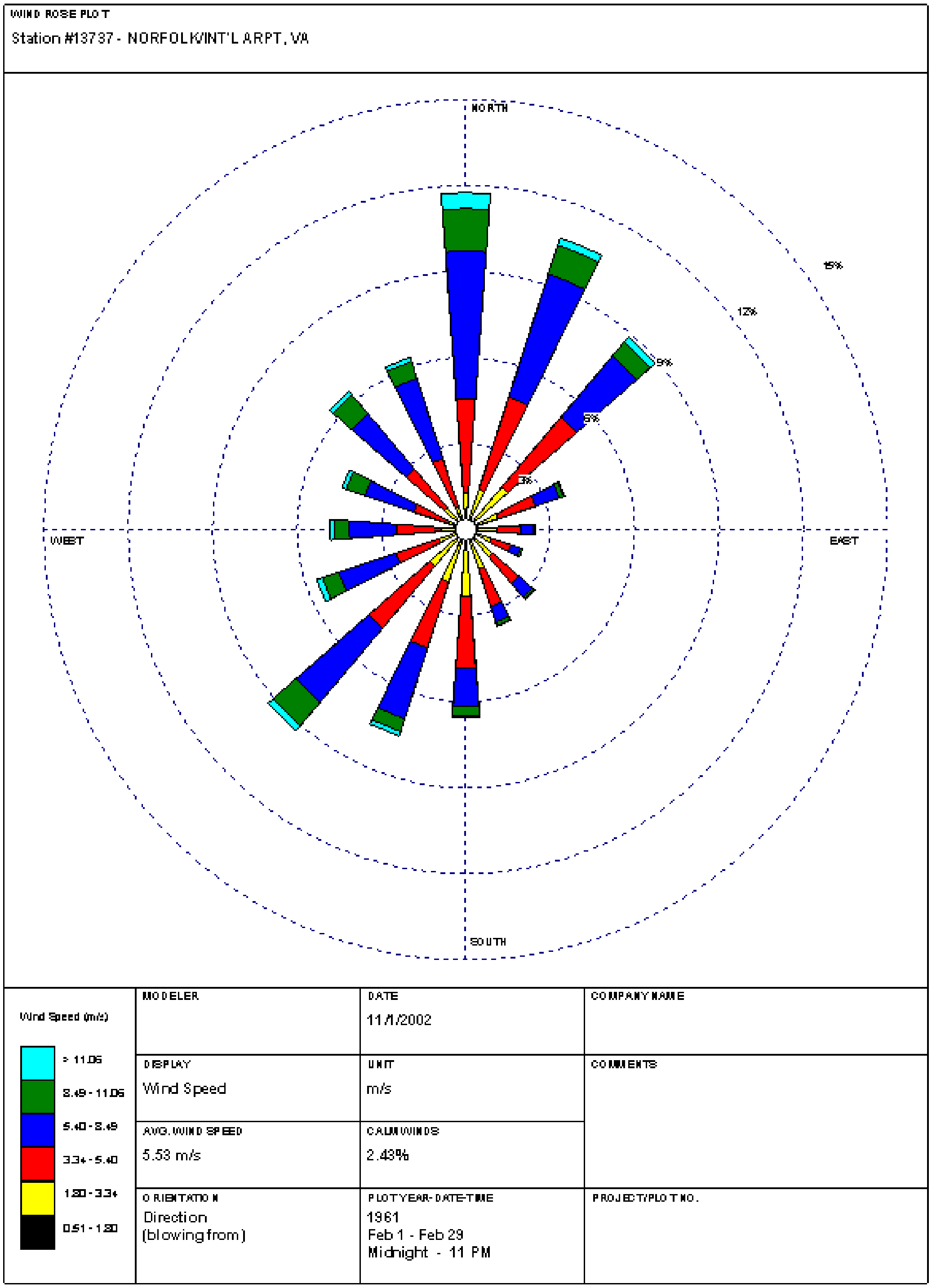
Jan 1 - Jan 31
Midnight - 11 PM
PROJECT/PLOT NO.


WIND ROSE PLOT
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SOUTH
WEST
EAST
3%
6%
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0.51 - 1.80
MODELER
DATE
11/1/2002
COMPANY NAME
DISPLAY
Wind Speed
UNIT
m/s
COMMENTS
AVG. WIND SPEED
5.53 m/s
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ORIENTATION
Direction
(blowing from)
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Feb 1 - Feb 29
Midnight - 11 PM
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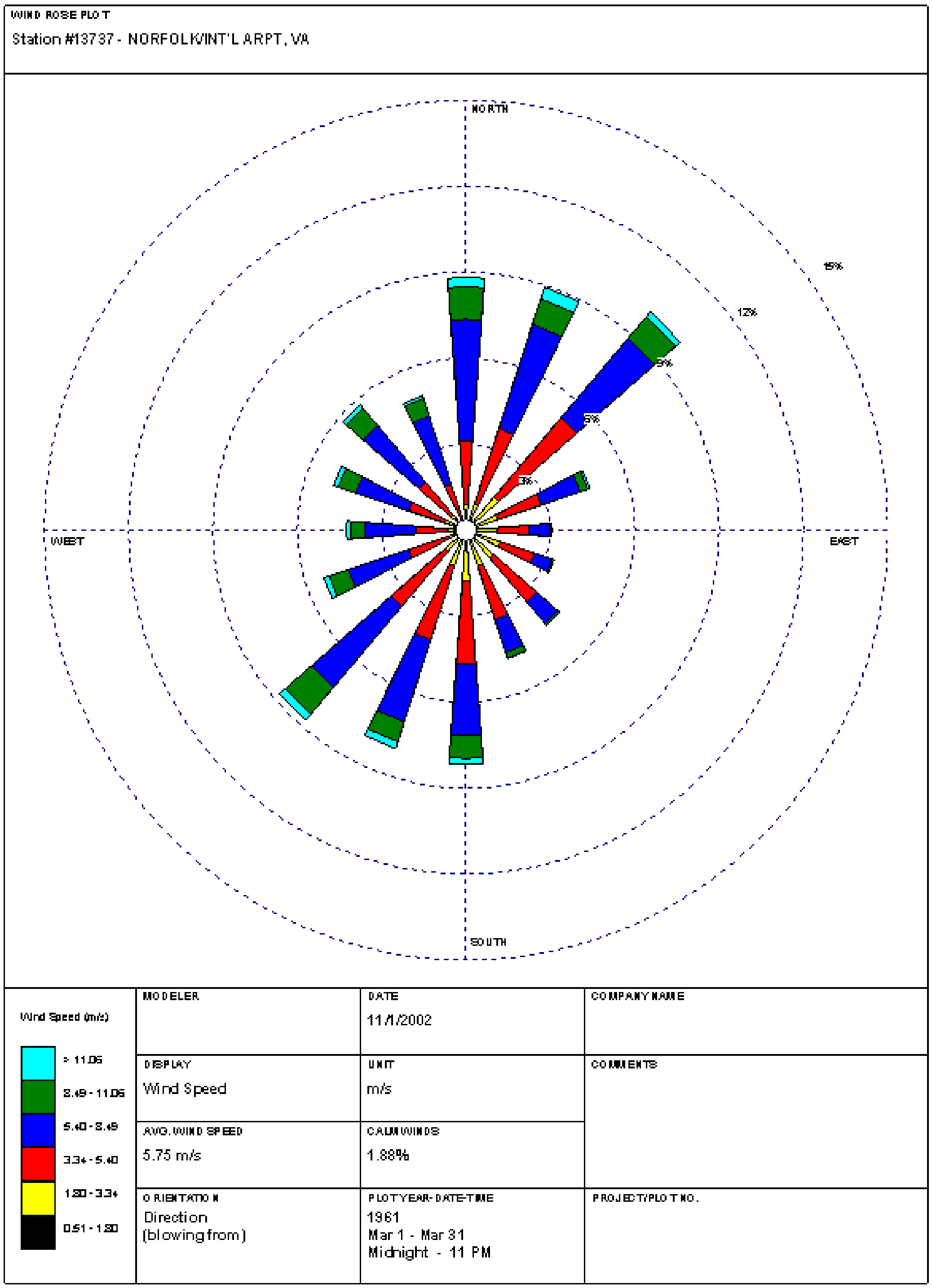
WIND ROSE PLOT
Station #13737 - NORFOLK/INT'L ARPT, VA
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EAST
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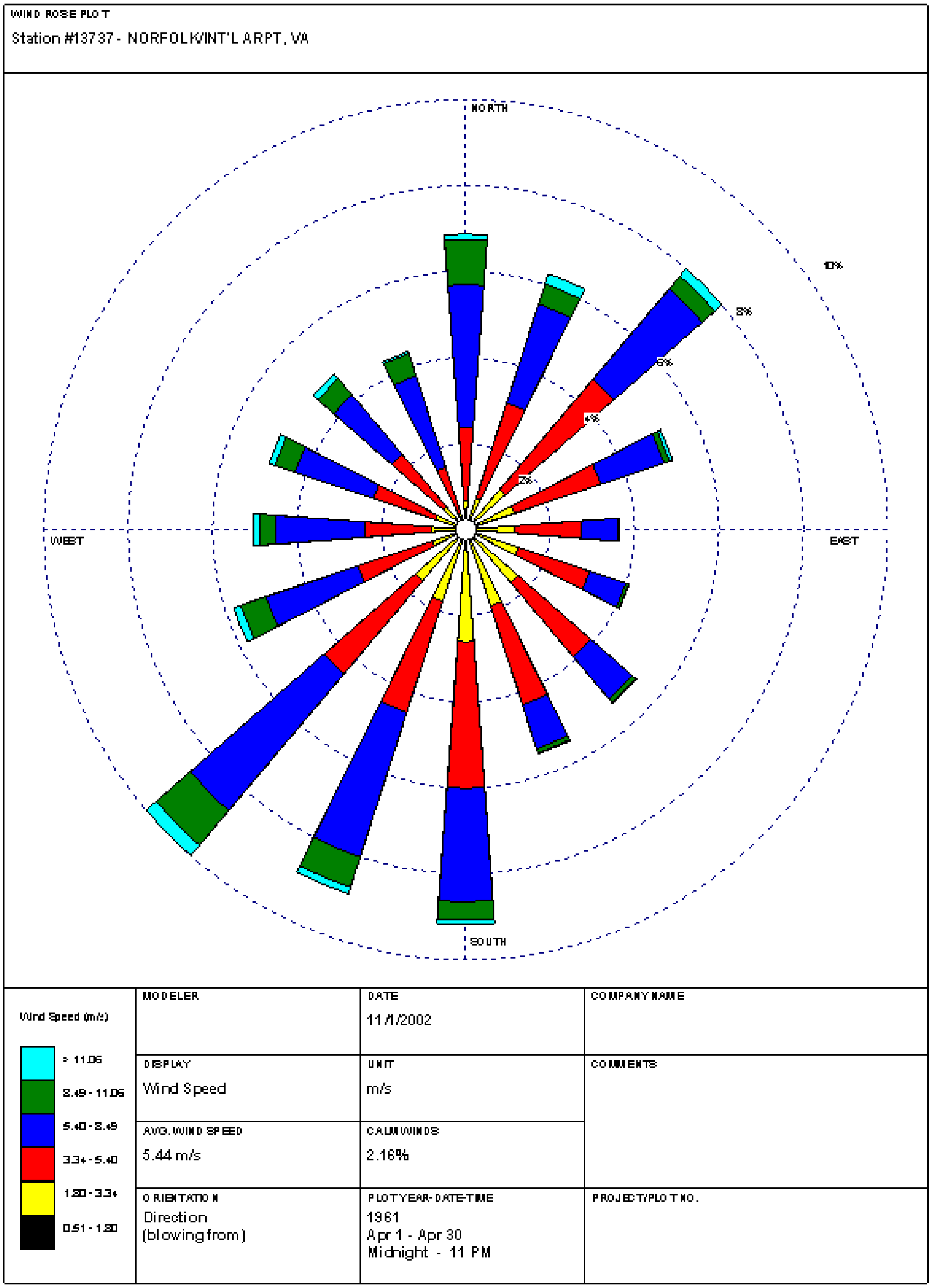
MODELER
DATE
11/1/2002
COMPANY NAME
DISPLAY
Wind Speed
UNIT
m/s
COMMENTS
AVG. WIND SPEED
5.75 m/s
CALM WINDS
1.88%
ORIENTATION
Direction
(blowing from)
PLOT YEAR-DATE-TIME
1961
Mar 1 - Mar 31
Midnight - 11 PM
PROJECT/PLOT NO.


WIND ROSE PLOT
Station #13737 - NORFOLK/INT'L ARPT, VA
NORTH
WEST
EAST
SOUTH
10%
8%
6%
4%
2%
Wind Speed (m/s)
> 11.06
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MODELER
DATE
11/1/2002
COMPANY NAME
DISPLAY
Wind Speed
UNIT
m/s
COMMENTS
AVG. WIND SPEED
5.44 m/s
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(blowing from)
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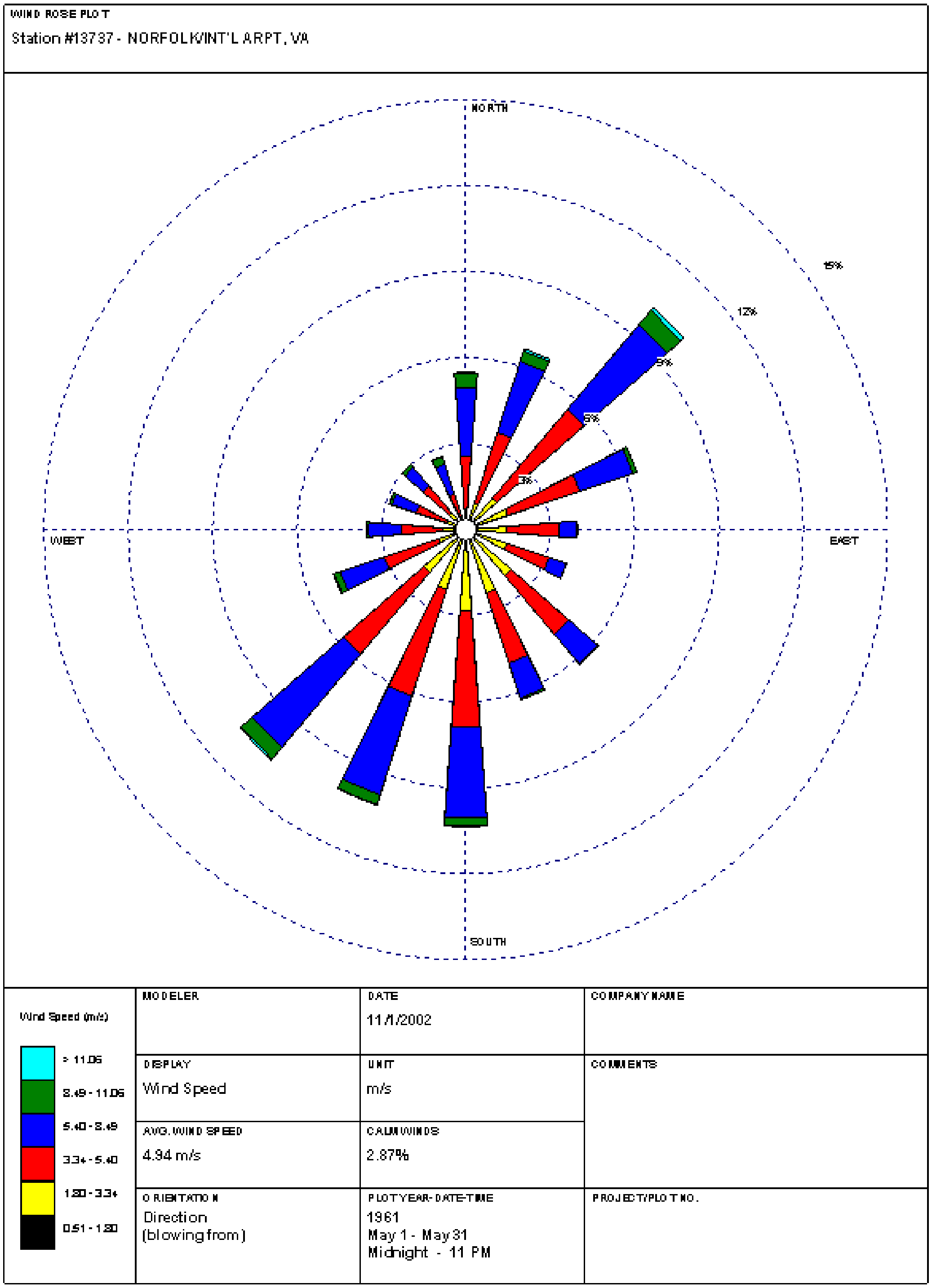
WIND ROSE PLOT
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EAST
SOUTH
15%
12%
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6%
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> 11.06
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MODELER
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11/1/2002
COMPANY NAME
DISPLAY
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UNIT
m/s
COMMENTS
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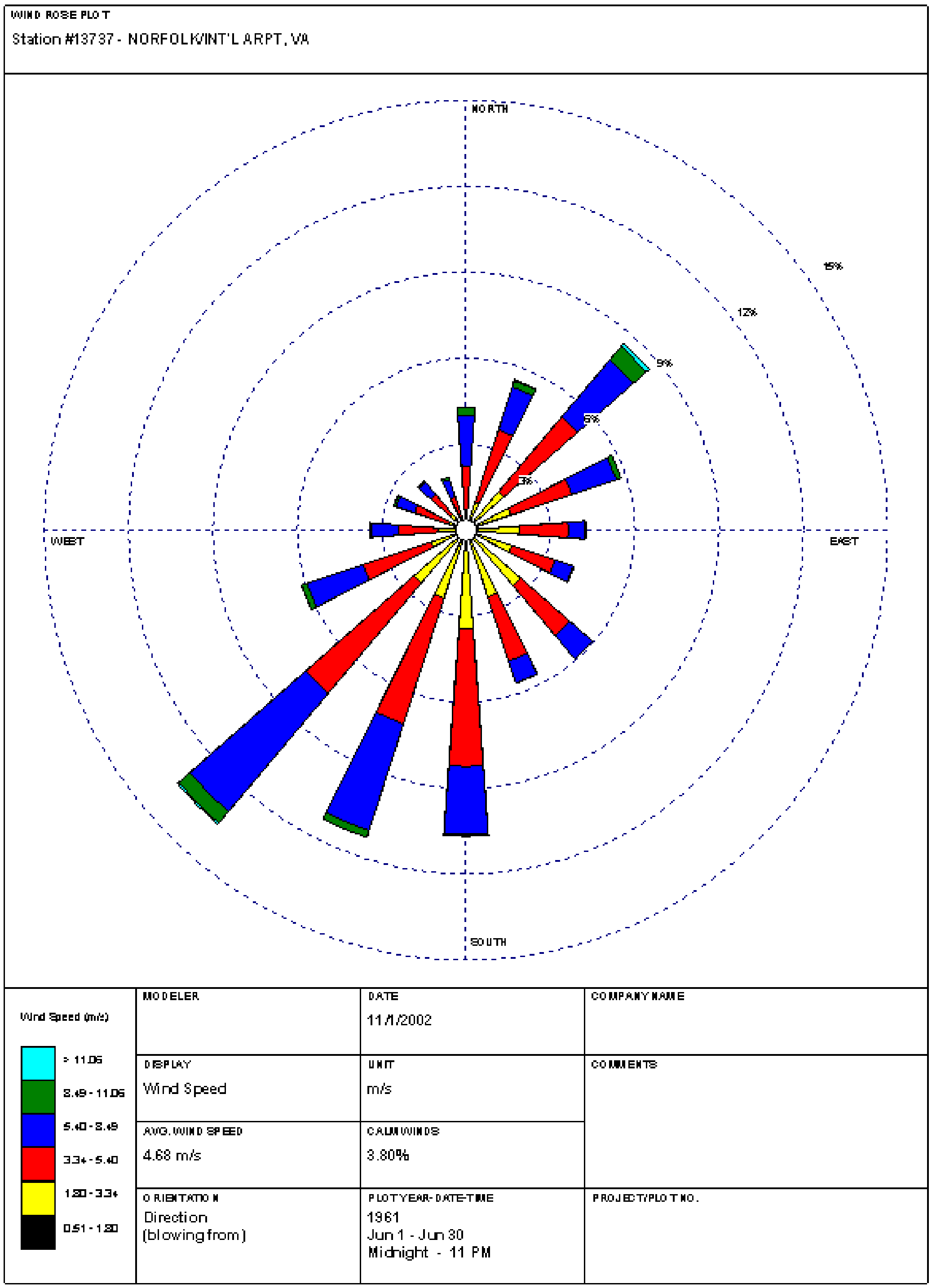
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Wind Speed
UNIT
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COMMENTS
AVG. WIND SPEED
4.68 m/s
CALM WINDS
3.80%
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Direction
(blowing from)
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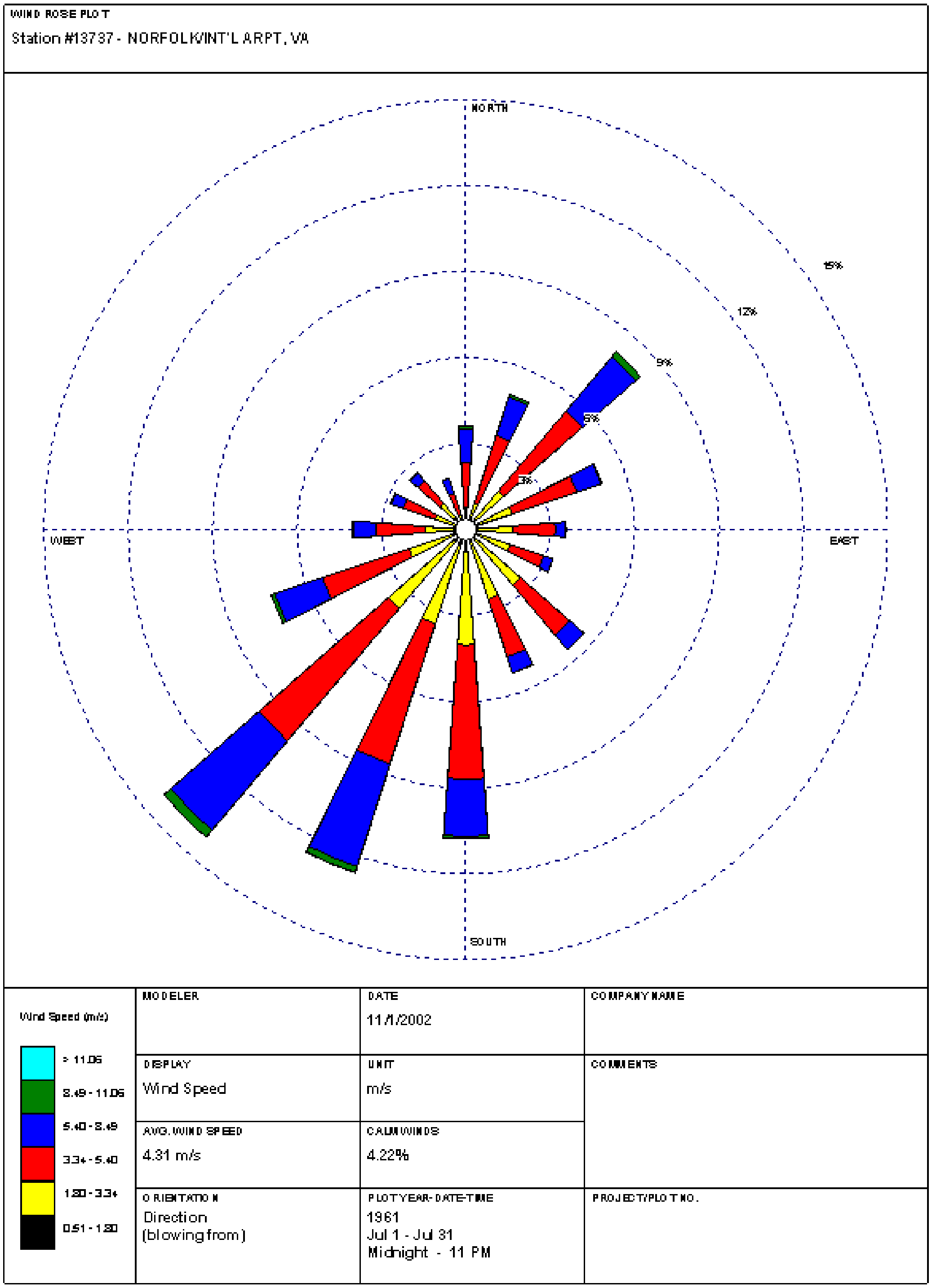
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COMPANY NAME
DISPLAY
Wind Speed
UNIT
m/s
COMMENTS
AVG. WIND SPEED
4.31 m/s
CALM WINDS
4.22%
ORIENTATION
Direction
(blowing from)
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Jul 1 - Jul 31
Midnight - 11 PM
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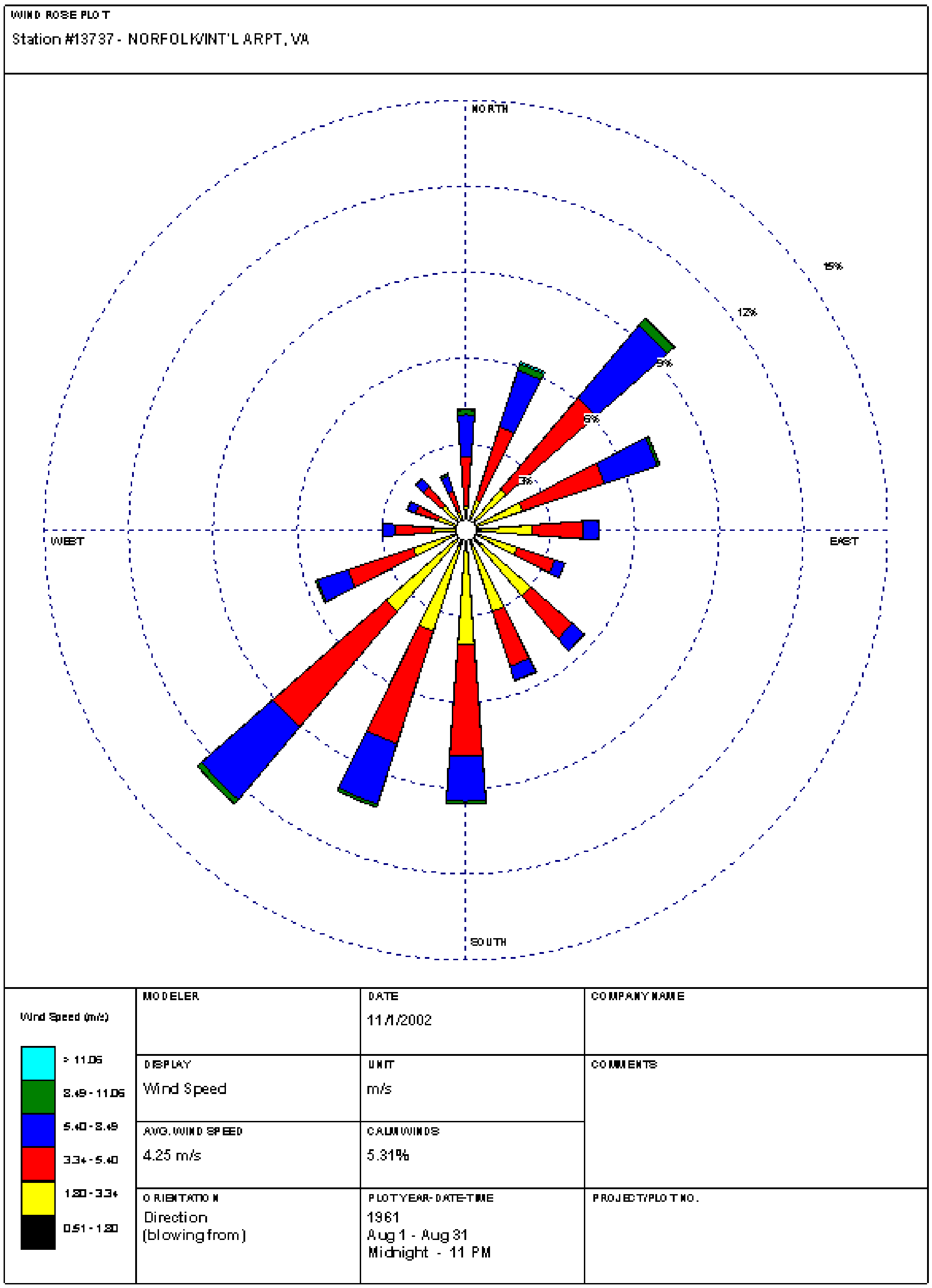
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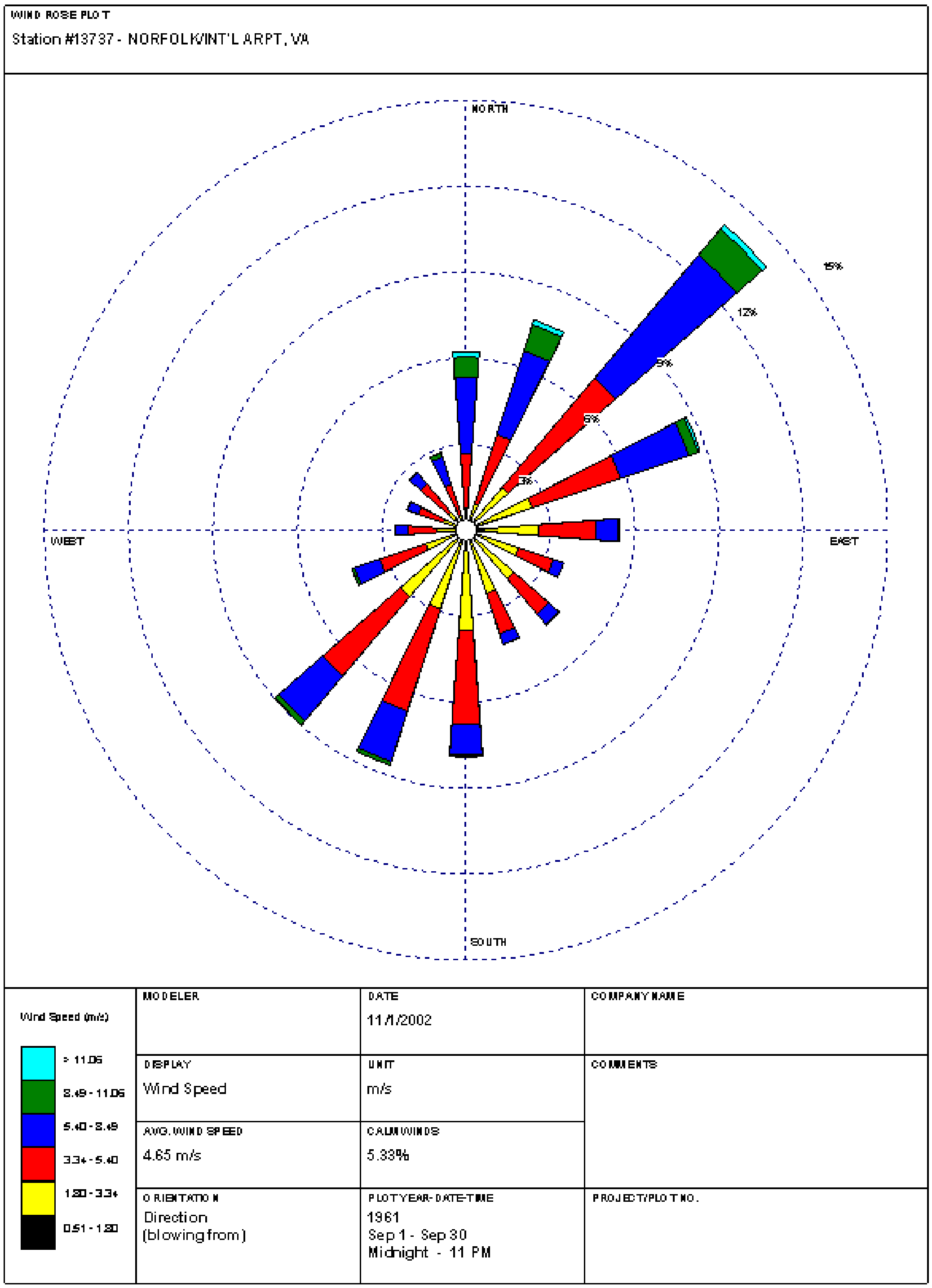
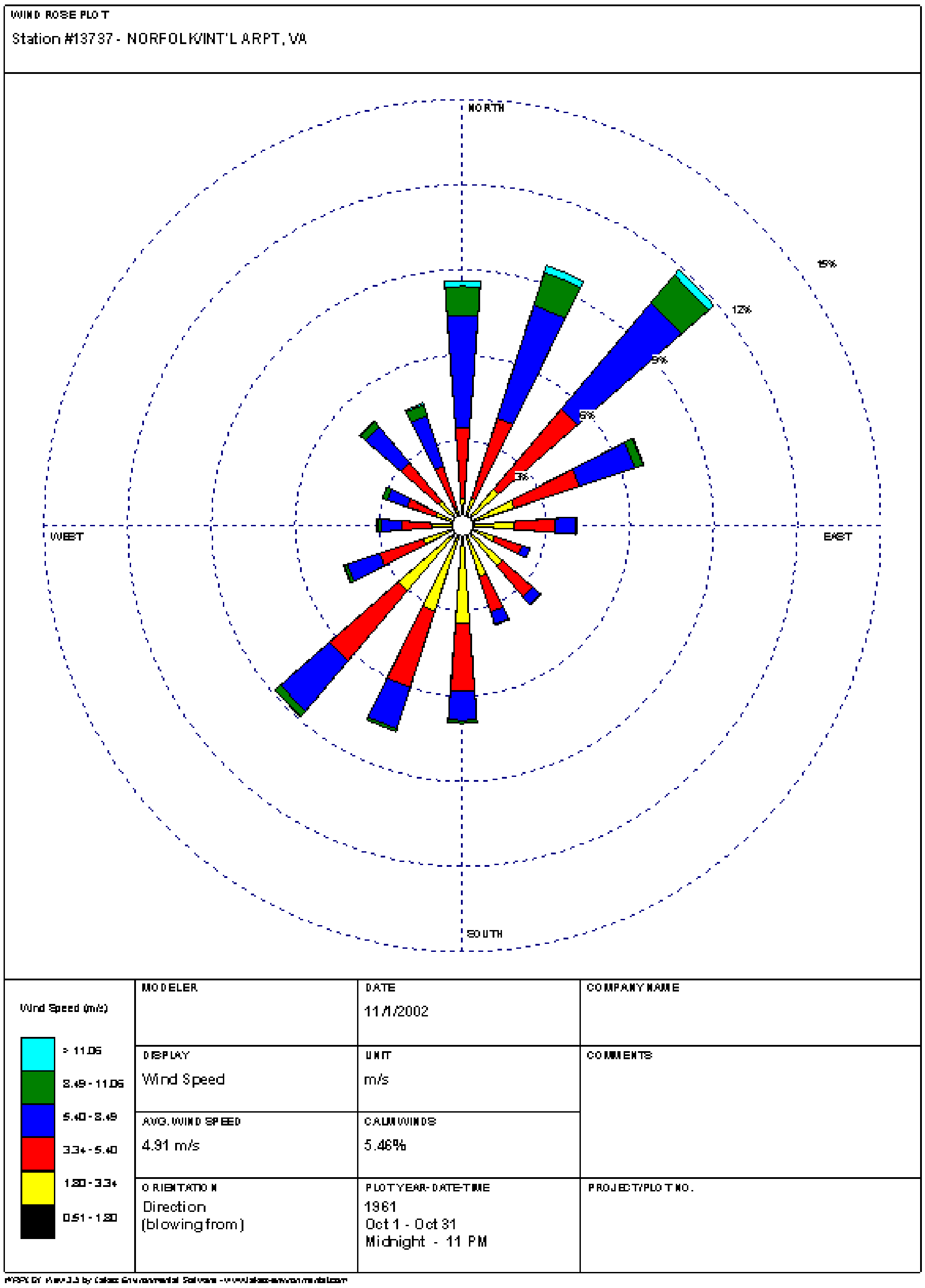
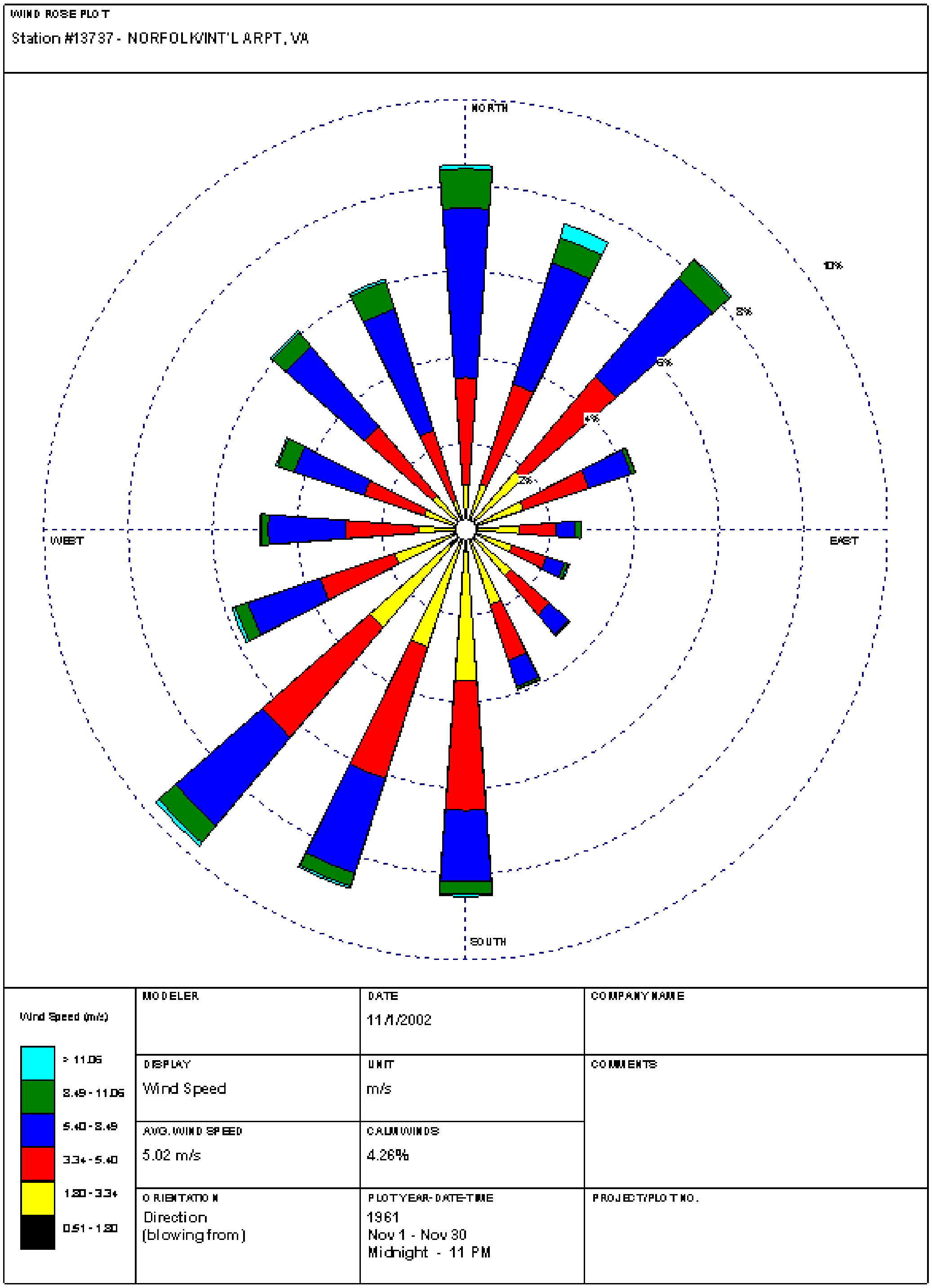
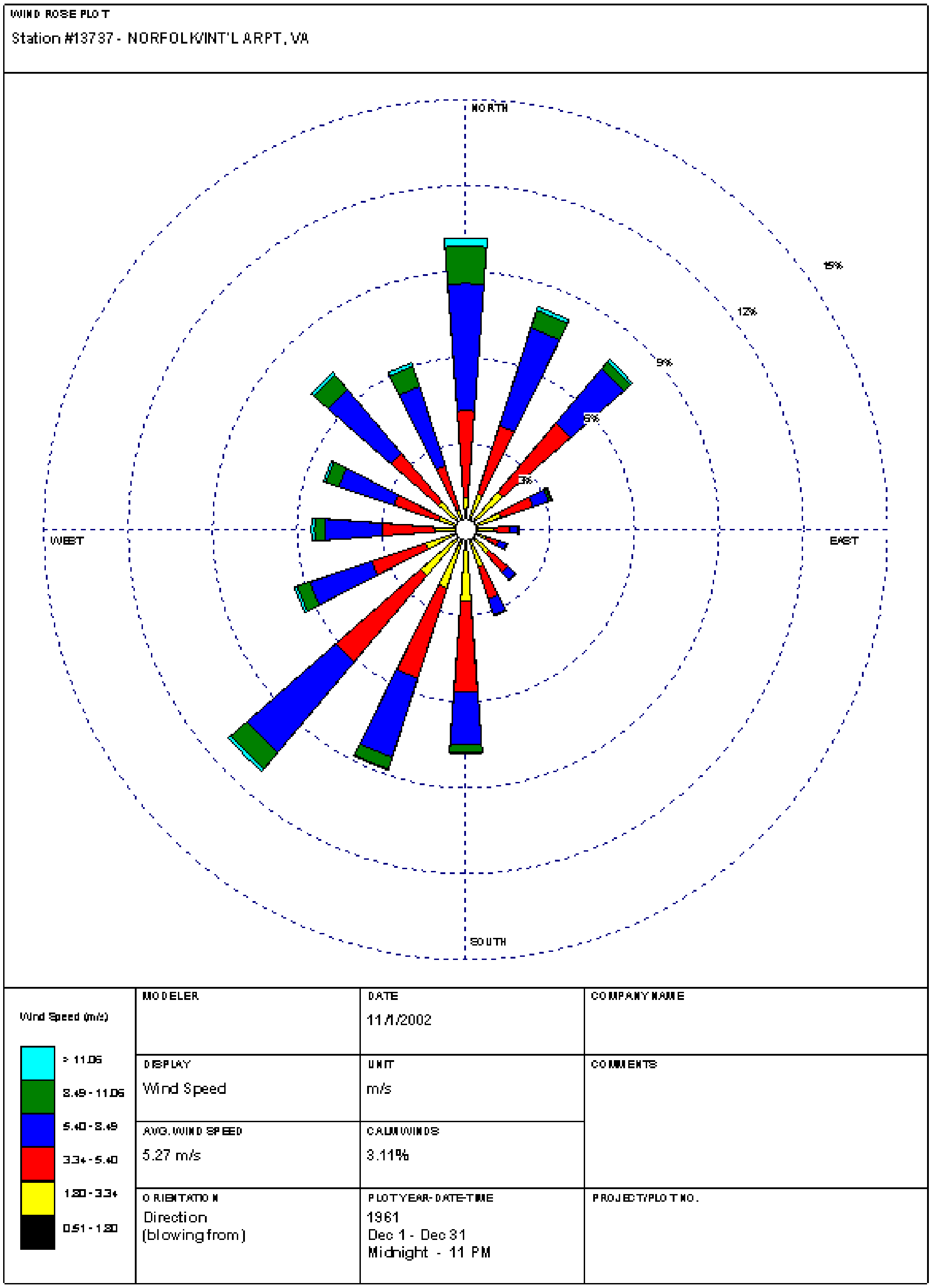
NORTH
SOUTH
WEST
EAST
3%
6%
9%
12%
15%
Wind Speed (m/s)
> 11.06
8.49 - 11.06
5.40 - 8.49
3.34 - 5.40
1.80 - 3.34
0.51 - 1.80
MODELER
DATE
11/1/2002
COMPANY NAME
DISPLAY
Wind Speed
UNIT
m/s
COMMENTS
AVG. WIND SPEED
4.25 m/s
CALM WINDS
5.31%
ORIENTATION
Direction
(blowing from)
PLOT YEAR-DATE-TIME
1961
Aug 1 - Aug 31
Midnight - 11 PM
PROJECT/PLOT NO.


WIND ROSE PLOT
Station #13737 - NORFOLK/INT'L ARPT, VA
NORTH
SOUTH
WEST
EAST
3%
6%
9%
12%
15%
Wind Speed (m/s)
> 11.06
8.49 - 11.06
5.40 - 8.49
3.34 - 5.40
1.80 - 3.34
0.51 - 1.80
MODELER
DATE
11/1/2002
COMPANY NAME
DISPLAY
Wind Speed
UNIT
m/s
COMMENTS
AVG. WIND SPEED
4.65 m/s
CALM WINDS
5.33%
ORIENTATION
Direction
(blowing from)
PLOT YEAR-DATE-TIME
1961
Sep 1 - Sep 30
Midnight - 11 PM
PROJECT/PLOT NO.


WIND ROSE PLOT
Station #13737 - NORFOLK/INT'L ARPT, VA
NORTH
WEST
EAST
SOUTH
15%
12%
9%
6%
3%
Wind Speed (m/s)
> 11.06
8.49 - 11.06
5.40 - 8.49
3.34 - 5.40
1.80 - 3.34
0.51 - 1.80
MODELER
DATE
11/1/2002
COMPANY NAME
DISPLAY
Wind Speed
UNIT
m/s
COMMENTS
AVG. WIND SPEED
4.91 m/s
CALM WINDS
5.46%
ORIENTATION
Direction
(blowing from)
PLOT YEAR-DATE-TIME
1961
Oct 1 - Oct 31
Midnight - 11 PM
PROJECT/PLOT NO.


WIND ROSE PLOT
Station #13737 - NORFOLK/INT'L ARPT, VA
NORTH
WEST
EAST
SOUTH
2%
4%
6%
8%
10%
Wind Speed (m/s)
> 11.06
8.49 - 11.06
5.40 - 8.49
3.34 - 5.40
1.80 - 3.34
0.51 - 1.80
MODELER
DATE
11/1/2002
COMPANY NAME
DISPLAY
Wind Speed
UNIT
m/s
COMMENTS
AVG. WIND SPEED
5.02 m/s
CALM WINDS
4.26%
ORIENTATION
Direction
(blowing from)
PLOT YEAR-DATE-TIME
1961
Nov 1 - Nov 30
Midnight - 11 PM
PROJECT/PLOT NO.


WIND ROSE PLOT
Station #13737 - NORFOLK/INT'L ARPT, VA
NORTH
SOUTH
WEST
EAST
3%
6%
9%
12%
15%
Wind Speed (m/s)
> 11.06
8.49 - 11.06
5.40 - 8.49
3.34 - 5.40
1.80 - 3.34
0.51 - 1.80
MODELER
DATE
11/1/2002
COMPANY NAME
DISPLAY
Wind Speed
UNIT
m/s
COMMENTS
AVG. WIND SPEED
5.27 m/s
CALM WINDS
3.11%
ORIENTATION
Direction
(blowing from)
PLOT YEAR-DATE-TIME
1961
Dec 1 - Dec 31
Midnight - 11 PM
PROJECT/PLOT NO.

appendix b

turbines

The following pages describe non-directional wind turbines that are ideal for an installation as proposed in this report. This product was used in the design of the Pearl River Tower in Guangzhou, China and was recommended to me by Kevin Cahill, P.E. of Skidmore, Owings and Merrill.

Elegant wind power has arrived with the new quietrevolution vertical axis wind turbine.

The quiet**revolution** QR5 is an innovative new wind turbine designed to work well in the urban environment, where wind directions change frequently and quiet, vibration free operation is critical.

The design arises from a combination of sound engineering principles and state-of-the-art aerospace technology. Form follows function to create an elegant and visually engaging product that is easy to integrate with existing buildings.

Key Product Advantages:

- The quiet**revolution** QR5 differs from a horizontal axis wind turbine (HAWT) in that it doesn't need to change its orientation to track the wind.

- QR5's sophisticated control system takes advantage of gusty winds: an innovative predictive controller learns about the site's wind conditions over time to further improve the amount of energy generated.

- The blade tip speed is much lower than on a similarly rated HAWT so less noise is produced.

- The helical blade design results in a very smooth operation that minimises vibration and further reduces acoustic noise.

- QR5 boasts a light and durable carbon fibre structure conceived using cutting edge computer design and modelling.

- QR5 is easy to integrate into existing structures due to its compact shape.

- The turbine is rated at 6kW and will have an expected output of 9600 kWh per year at an average annual wind speed of 5.9 m/s will provide 10% of the energy for a 600 m^2 office building.

- In addition QR5 will save around 4200 kg of carbon dioxide emissions every year.

The QR5 turbine costs £25,000 including generator, anemometer, accelerometer and peak power tracking hardware. Additional costs include control electronics, mast and mounting, and mechanical installation. Total costs typically range from £30,000-£35000 per installed turbine. The QR5 has a design life of 25 years and comes with a two year warranty.

Winner of the Building Magazine Sustainability Award for Product Innovation and the Bottom Line Design Award 2007

www.quietrevolution.co.uk

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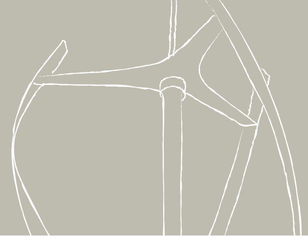
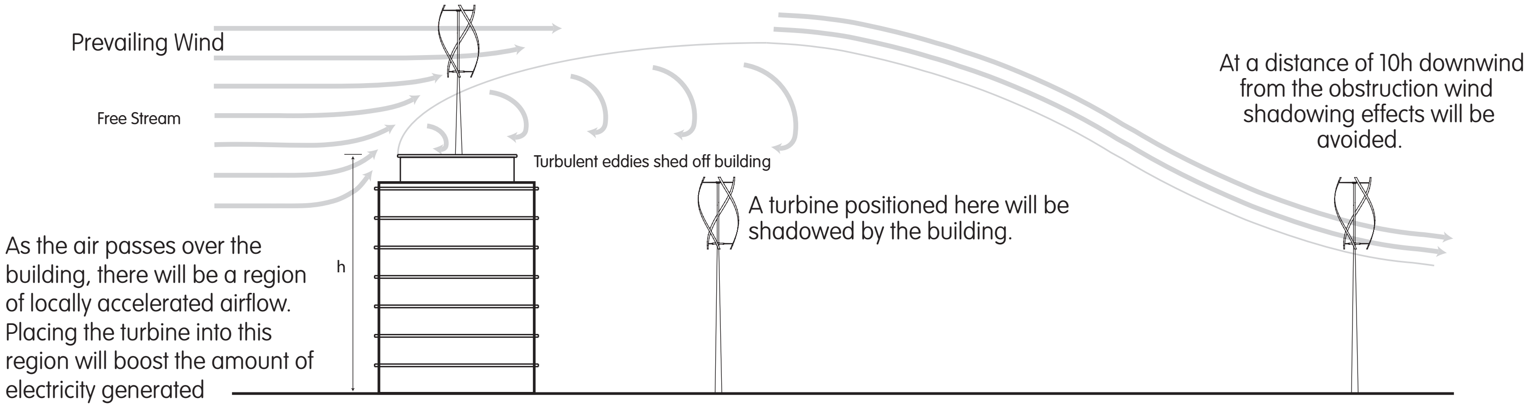
Registered in England No. 5405104
VAT No. 882 3393 02



quietrevolution
an XCO2 innovation

Optimising Wind Energy in the Urban Environment

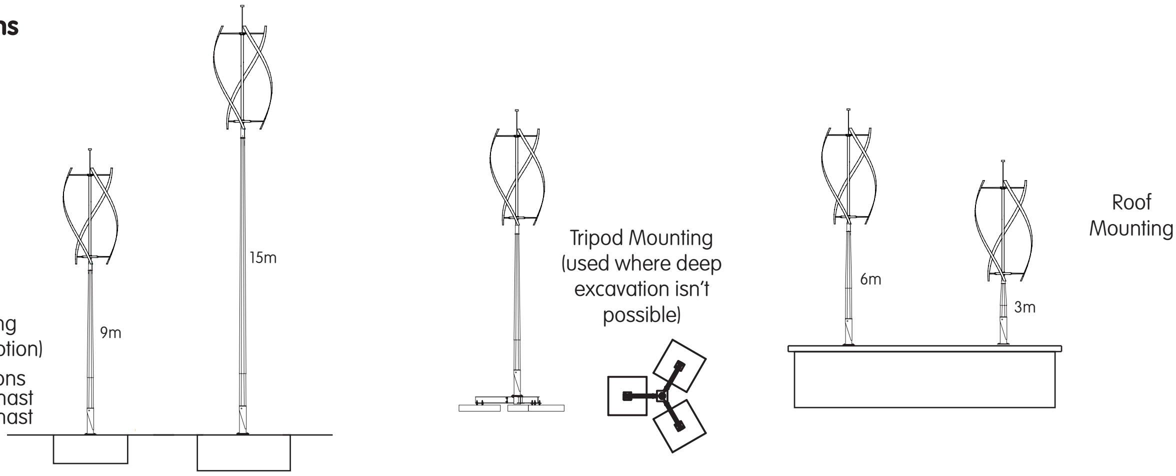


Turbine Spacing

Multiple turbines should be placed at least 3 rotor diameters (9.3m) apart to eliminate interference.

Closer rotor spacing can be achieved by staggering the mast height.

Installation Options



Technical Specification

Physical dimensions: 5m high x 3.1m in diameter

Generator: Direct drive, mechanically integrated, weather sealed permanent magnet generator

Power control: Peak power tracking constantly optimises turbine output for all sites and windspeeds

Operation mode: Max wind speed: 16 m/s; Min wind speed: 4 m/s

Rotor construction: Carbon fibre and epoxy resin blades and connection arms

Brake and shutdown: Over-speed braking above 14 m/s wind speed, auto shutdown in high wind speeds (above 16 m/s)

Design life: 25 years (annual inspections recommended)

Roof mounting: Minimum recommended height above buildings: 3m

Tower mounting: Minimum mast height: 9m to bottom of blades. Demountable models are also available for temporary installations

Remote monitoring: Event log can be accessed via GSM Dial up. Remote monitoring stores operation and kW hours of electricity generated

Warranty: Two years on components

Cost of turbine: £25,000

Installation cost: Around £5,000-£10,000 (site dependent)

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