Final report

1.1 Project details

Project title	IEA Wind Task 27 – Mærkning af små vindmøller IEA Wind Task 27 – Small Wind Turbine Labels
Project identification (program abbrev. and file)	Journal nr.: 64013_0550
Name of the programme which has funded the project	Energiteknologisk Udviklings- og Demonstrationsprogram (EUDP)
Project managing company/institution (name and address)	Danmarks Tekniske Universitet DTU, Institut for Vindenergi Risø Campus, Frederiksborg Vej 399, 4000 Roskilde
Project partners	IEA Corporation: Austria, China, Denmark, Ireland, Japan, Korea, Spain, United States.
CVR (central business register)	30060946
Date for submission	August 14 2016. Project period: 12.2013 – 04.2016

1.2 Short description of project objective and results

IEA Task27 extension (Small Wind Turbines in High Turbulence Sites) has its focus on the research needs for understanding small wind turbines and their performance in environments of high turbulence including the built-environment. The subtasks are: Continue the international Small Wind Association of Testers (SWAT) and develop a Recommended Practice for Design of Small Wind Turbines in the Built Environment. The final content and title of the extended task 27 is "Small Wind Turbines in High Turbulence Sites". As Small wind turbines normally are located in built environment it is important to study loads and production. The Danish contribution is measurement of wind conditions in high turbulence, the fence experiment to support CFD verification. All measurements and results are public available.

IEA Task27 extention (små vindmøller på høj turbulentes sites) har fokus på de forskningsmæssige behov for at forstå små vindmøller og deres ydeevne i miljøer med høj turbulens, herunder bymiljøer. Delopgaverne er: Fortsat udvikling af en international forening for test af små vindmøller (SWAT) samt udvikle en anbefalet praksis for design af små vindmøller på turbulente opstillingssteder og bymiljø. Det endelige indhold og titel på den udvidede task 27 er "små og mindre vindmøller i højturbulente placeringer". Da små møller normal placeres tæt på bygninger er det vigtigt at forstå vindlasterne og produktionen under de forhold. Det danske bidrag består af vindmålinger omkring et hegn til verificering af CFD beregninger. Alle målingerne og resultaterne heraf er offentligt tilgængeligt.

1.3 Executive summary

In 2009-2012 the IEA Task 27 was launched with two main objectives: "Development and Deployment of a Small Wind Turbine Consumer Label" including a Recommended Practices for Wind Turbine Testing and Evaluation "Consumer Label for Small Wind Turbines" and the Development of the "Small Wind Association of Testers" for information and experiences exchange between entities interested on SWT testing and evaluation.

After these objectives were accomplished, ref /6/, some countries were still interested to extend the IEA wind Task 27 with some new issues as all related to small wind for urban integration and the special wind conditions found in this urban environment and its effect on wind resources assessment methodology.

The new idea is to include some recommendations for wind resource assessment and small wind turbines design and test for urban environments as final target of this extension period of task 27. The task extension proposal and the work program were approved at the ExCo 70 meeting in Tokyo October 2013, and supported by EUDP from December 2013 to April 2016.

Finally the title of the extended task 27 is Small Wind Turbines in High Turbulence Sites.

Most small wind turbines are not designed for a roof or built environment, or urban setting since anything blocking the wind in the dominant wind direction creates high turbulence, the most difficult wind condition for all wind turbines of all sizes.

The main goals of IEA Task 27 are to offer the opportunity to share technical experience on measuring and modelling urban and peri-urban wind resources, learn about emerging trends, and gain practical experience on turbine performance.

The expected results are:

1. Develop a Recommended Practice that provides guidelines and information on micro-siting of small turbines in highly turbulent sites (urban/suburban setting, on a rooftop, in a forested area, etc.) and the possible energy production for these sites.
2. Provide data and results from this proposed work along with guidance for a new design classification with specific guidance on I15 or similar variables for IEC 61400-2 and new information on external conditions i.e. the normal turbulence model & extreme direction change found in Section 6 of 61400-2.
3. Compare existing power performance test results (typically from accredited power performance test organizations) to power performance results taken in highly turbulent sites.
4. Develop preliminary VAWT Simplified Loads Methodology that should be validated and used in consideration of the fourth edition of IEC 61400-2 (not scheduled to start until 2018).

The work of Task 27 started late in 2012 with a planned duration of 4 years, but it was extended 1 year (to the end of 2017). Work is proceeding on the documentation of activities through the development of case studies, which are intended to capture technical findings and research results.

The five Working Packages are as follows:

- WP 1: Deploy Small Wind Association of Testers (SWAT) consumer label
- WP 2: Analyze and model a highly turbulent wind resource
- WP 3: Collect "new" wind resource and turbine power performance data from rooftop/complex terrain test sites
- WP 4: Develop a Recommended Practice on micro-siting of small turbines in highly turbulent sites

- WP 5: Prepare for standards by developing a new approach to VAWT simplified loads methodology (SLM) and conduct other multi-year research needed to improve the fourth revision of the IEC 61400-2 standard.

During the course of time there have been developments in the projects and the technical content of the work packages:

- Development of guidelines for designing and installing small wind turbines for the built environment. (urban, peri-urban)
- Development of an accurate procedure for AEP of Small Wind Turbines operating on highly turbulent wind sites.
- Validated Turbsim and CFD models (CFX ANSYS, Open FOAM) for optmized siting wind turbines in highly turbulent sites.
- Link of CFD codes with Mesoscale Wind Numerical models and SWT Aeroelastic models

Meeting hold during 2014 and 2016

- February 12-13, 2014 Virtual meeting
- May 8-9, 2014 Louisville CO (USA)
- August 25-27, 2014 Small Wind Associations of Testers Conference
- August 28-29, 2014 Zhang-Bei, Herbei Provice China
- January 2015 Virtual meeting
- April 2015 Wien, Austria IEA Task 27 committee meeting
- July 2015 Virtual meeting
- September 4, 2015 Bolder SWAT Conference
- September 5, 2015 Boulder US meeting
- January 24, 2016 Virtual meeting
- April 26, 2016 Virtual meeting (IEA Task 27 committee met in Taiwan)
- September 5-8, 2016 Nordic Folkecenter Denmark

The September 2016 meeting takes place after this EUDP project has been finalized. However presentations will be uploaded as planned.

At each meeting presentation is given by the participants, ref /8/. There are typically between 10 and 20 experts and presentation at each meeting.

IEA Task 27 Meetings in 2015

During 2015, Task 27 activity was significant. Six meetings were conducted, which included four virtual meetings and two face-to-face meetings. The first two virtual meetings were held January and the second virtual meetings was held July Sixteen experts from Australia, Austria, Argentina (Observer), China and Taiwan, Korea, Ireland, Denmark, Spain, and the USA attended the first virtual meetings. Ten experts from six countries (Austria, China, Ireland, South Korea, Spain, and the USA) participated in the second virtual meetings. All virtual meetings were hosted by NREL.

The University of Applied Sciences Technikum Wien hosted the first face-to-face meeting in Vienna (Austria) on 14 and 16 April at the Department of Renewable Energy. Fifteen experts attended this meeting, representing eight countries: Austria, China, Denmark, Germany (Observer), Ireland, Spain, USA, and Australia (Observer). Fourteen presentations were given. On 15 April, the Austrian Small Wind Energy Association hosted a meeting at the university facilities. Another side meeting held the morning of 16 April was a meeting of the IEC RE WE-OMC WG502 small wind turbine subgroup.

NREL hosted the second face-to-face IEA Task 27 meeting of 2015 at the National Wind Technology Center (NWTC) on 9-11 of September in Louisville, Colorado (USA).

More than 20 experts participated, many from the USA but also some from Austria (virtual), Argentina (virtual), Australia (virtual), China, Ireland, Korea, Japan (virtual), and Spain. Over 30 presentations were given on unaccredited and accredited testing of small wind turbines, national standards and certification schemes, new results from CFD studies of built-environment wind turbines, new approaches to gathering yaw measurements for built-environment wind turbine testing, and lessons learned from small wind turbine testing.

This meeting was followed by the 4th Annual Small Wind Association of Testers (SWAT) Conference on 14-16 September at the NWTC (also in Boulder).

Technical Results Summary

CFD Model Results

CIEMAT, Spain gave a presentation focused on the results of a CFD simulation of the wind flow around buildings with the case study of a CEDER-CIEMAT building in Soria. Measurements have been collected at the Soria site to validate the CFD simulations. The turbine location on the roof may be important in determining rooftop wind viability. For this reason, a detailed CFD study is planned that uses a mesh very close to the building with small cells. LES was considered, but it is too expensive; RANS models were applied instead.

Zentralanstalt für Meteorologie und Geodynamik, Austria gave a presentation about climatological aspects and wind flow simulation for Vienna. This presentation showed the results of the application of INCA, a numerical weather prediction model for Austria with a resolution of 100 x 100 m that has been validated with an extended observational network and use of SODAR for urban areas. The model was validated based on measurements using heated ultrasonic anemometers.

Murdoch University, Australia presented about using CFD to gain insight into the turbulence inflow conditions for a small wind turbine on a building rooftop. This study assessed the combination of CFD package and wind atlas software as a wind resource assessment tool for a small wind turbine installation on a rooftop in the built environment. The tool was used to investigate wind speed and direction on the rooftop and identify the optimal location for installing the turbine, taking into account zones of wind acceleration, recirculation, and blockage. The results of the study show CFX provides reasonable accuracy for simulating flow around a rectangular obstacle and the combination of a CFD package with a wind atlas software such as WAsP provides a promising tool for wind resource assessments for small wind turbines on buildings. The model used the Kaimal filter with a standard deviation found in urban environment. There seems to be much better correlation for 5 m/s winds.

Shandong University, China gave a presentation on the wind field around a rectangular CFD model of a flat roof. A roof with a turbine shows areas of flow disruption. If multiple turbines are to be placed on a roof, the downstream turbines should be increased at least 4 m higher than upstream turbines.

Austria Institute of Technology, Austria gave a presentation on two projects, IPPONG and STEP-A. IPPONG uses CFD for optimal positioning of small wind turbines in urban areas. The roof and surroundings area were modelled with four measurements points at the roof corners, which were assumed as boundary conditions. The CFD model simulates seven wind directions and estimated performance using a cubic function of simplified geometry. The structured surge cases use an annual average, which is the basis of an estimation of energy yield. This plot can influence where to place a turbine on the roof.

The second project, STEP-A, studies the economic potential of small wind turbines. Focusing on the CFD part of this project only and based on a dominant wind direction, the building's impact on the flow can be modelled. The model estimates boundary layer thickness of city structures and gives guidance on the needed turbine height to get above the boundary layer of the roof. Based on FLUENT, time-independent simulations can be evaluated using wind speed, wind directions simulated in MISCOM.

Turbulent-Site Test Results

INER, Taiwan gave a presentation on high-rise rooftop testing at National Taiwan University. They have found the capacity factor on the roof was 0.09%. Professor Lee from the National Taiwan University collected and analyzed rooftop measurements on using 3-D sonic anemometers.

KETEP, Republic of Korea gave a presentation on rooftop testing on Jeju Island for a site surrounded by water on three sides. Initial results show turbulent kinetic energy is almost double in the direction where the wind comes over the building before it sees the 3-D anemometer.

NREL, USA presented on the progress of the case study of the NASA Johnson Space Center Building 12 in Houston, Texas (USA). Relevant recommendations for the built-environment wind turbine measurement were given, including resource assessment and turbine response. Very low wind speeds have been found on this low-rise building, as well as very low capacity factors, all ranging less than 0.01%.

UASTW, Austria presented an approach to evaluating a VAWT and HAWT in an urban rooftop environment (ENERGYbase) and a rural environment (Energy Research Park in Lichtenegg; shown in Figure 3). The ENERGYbase site uses SODAR (100m away from the roof) and 2-D measurements to characterize the wind resource and better understand the effects of turbulence. Lichtenegg is an open small wind turbine test site with rolling hills. Meeting participants visited the site during face-to-face meeting #14. Test results gathered at Lichtenegg and at the ENERGYbase will be the basis of comparison of production and turbulence characteristics.

DTU, Denmark has set up a "fence experiment," a 2-D structure to validate wind resource measurements with WaSP. Two sonic anemometers are used to create the wind profile and wind direction on both sides of the fence. Currently the fence, made with wood, has a 100% blockage; wood can be removed to create a lower blockage level.

Peri-urban Turbulent Production

DKiT, Ireland gave an overview of the Irish small wind turbine field test data and presented a comparison. All data for wind speed and wind direction are 2-D measurements with a 1-minute sample rate. There are 16 SEAI small wind turbine datasets for different turbine models, all sited in different peri-urban sites. Data sets are being chosen to minimize the turbine effects and maximize site comparison. Two data sets were analysed to show variations in site turbulence levels: a good site with an I5 of 0.18 and I15 of 0.16 and a poor site with a I5 of 0.21 and I15 of

0.18. (Task 27 experts have been discussing whether an I5 is a better turbulence parameter for active small wind turbines compared to an I15.)

NREL, USA presented an interesting case study of four wind turbines roof-mounted on a high-rise in Portland, Oregon (USA). These turbines were located directly above the penthouse units and integrated into the building design early with extensive pre-construction resource assessment prior to installation. Based on production data, the four small wind turbines had a 7% capacity factor. The building owners still consider the project successful because of the positive recognition the building received.

Complex Terrain Prediction Methods

Inner Mongolia University of Technology, China gave a presentation on ARCGIS, a tool that can handle complex terrain and provide turbine production predictions.

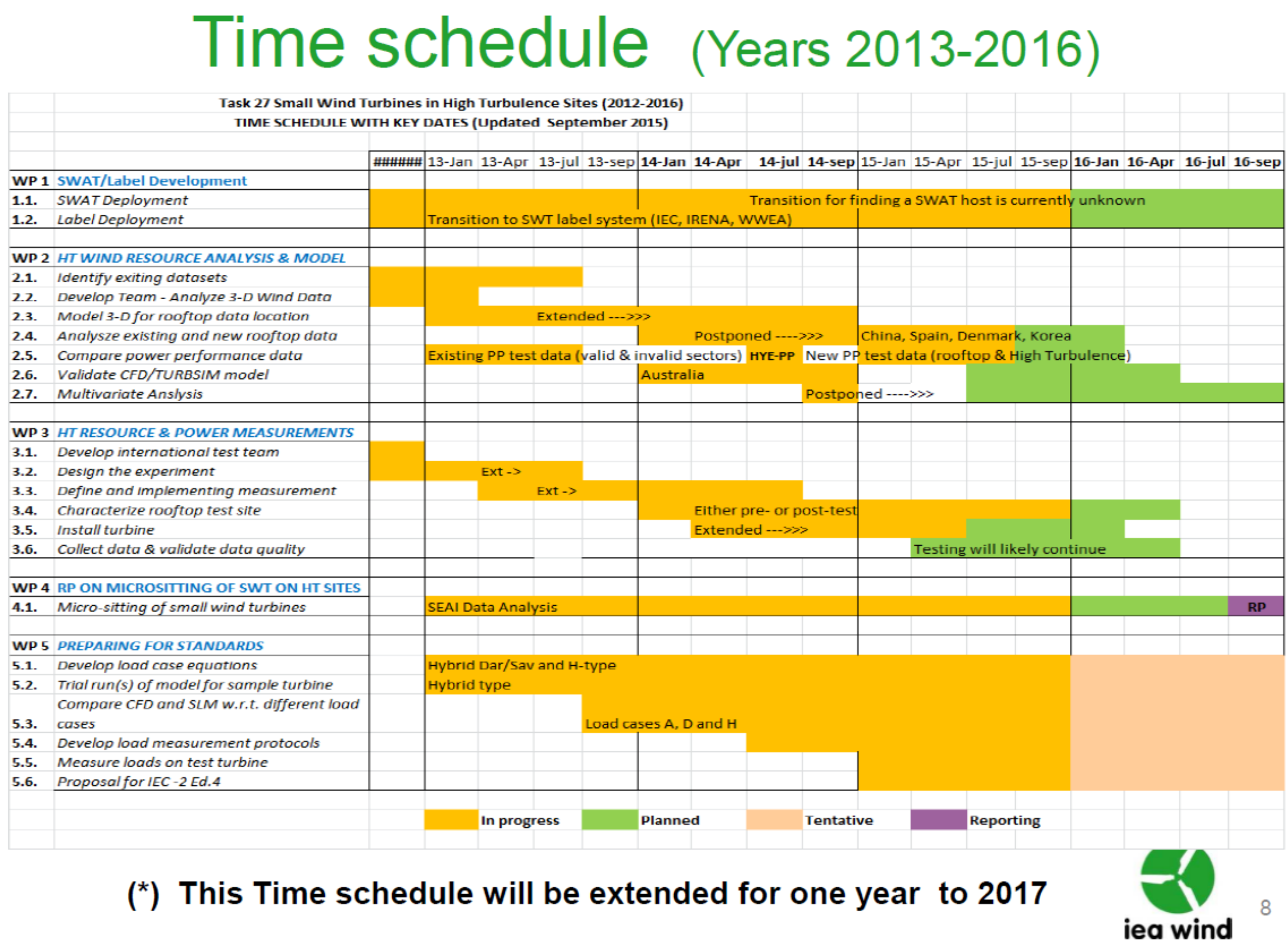
NREL, USA gave a summary of a distributed wind resource assessment meeting. The model-based approach currently accounts for the majority of industry effort to understand a site's wind resource. While measurements are important and valuable, the challenges with cost and deployment time currently preclude widespread adoption of measurement campaigns.

Technical Results for 4th Revision of IEC 61400-2

Further progress is being made by INER, Tiawan on developing a new approach and validating this approach with measurements for a VAWT simplified load methodology. This effort is focused on two VAWT configurations: Darrieus and Savonius small wind turbines.

Time schedule

The time schedule was updated end September 2015. This indicates the delays in the IEA task 27. The present EUDP project that supports the work was concluded by end of April 2016. This leaved the WP4: Recommended Practice on micro-siting of small turbines in highly turbulent sites incomplete at this time of the project. Input from Denmark is at present under preparation.



1.4 Project objectives

The IEA Task 27 extended project objectives are:

1. Promote the technical exchange of small wind testing approaches and methodologies.
2. Deployment of the international consumer label for Small Wind Turbines.
3. Evaluation of 'existing' 3-D wind data Evaluation and comparative analysis of existing accredited power performance results.
4. Identification of software tools that can be used to help understand the complex flow found in an urban environment.
5. Validation of simple CFD models based on test data.
6. Identification of a common measurement and analysis approach.
7. Development of a draft of Recommended Practice, on "micro-siting of small turbines in highly turbulent sites"

The task was extended in 2013 through 2016 to explore issues of small wind turbines in turbulent environments (such as urban or complex terrain). The new effort will do three main things:

- It will develop a Recommended Practice on micro-siting of small turbines in highly turbulent sites (urban/suburban setting, on a rooftop, in a forested area, etc.) and the possible energy production for these sites.
- It will provide data and results for a new design classification with specific guidance on I15 or similar variables for IEC 61400-2 and provide new information on external conditions i.e. the normal turbulence model & extreme direction change found in Section 6 of 61400-2.

- It will compare existing power performance test results (typically from accredited power performance test organizations) to power performance results taken in highly turbulent sites.

1.5 Project results and dissemination of results

Task 27 is reporting to IEA on annual basics with annual publications.

The Label system provided by Task 27 ref. /6/ and now in use by IEC TC88 is very close and with links to IECRE.

Proposal of Agreement with the WWEA Small Wind to implement the SWT label in the www.small-wind.or web page

The task 27 work is the foundation for the work done in IEC61400-2 Small wind turbine design standards, and is much needed for the future revision of the standard.

In connection with the task 27 meeting there have been back to back meetings with the IECRE small wind standardization as well as national small wind conferences with presentation and participation by task 27 participants, ref /8/.

In Denmark the labelling system has provided a input to certification under the national certification scheme.

The shelter measurement of an obstacle (30x0.2x3m fence) was conducted at Risø's test site in Denmark and the WindScanner (lidar-systems) was used to measure the 3D wind vector on a vertical plane. The test was conducted during two periods: from March - April and from September - October 2015.

The following deliverables are available as a contribution to the IEA Task 27 project, including: a journal paper (in Wind Energy Science Journal ref /1/) "The fence experiment full-scale lidar based shelter observations", Peña et al (2016), and the measurements from the experiment are available at www.fence.vindenergi.dtu.dk.

The fence experiment serves as benchmark for evaluation of shelter models. Besides a report "Shelter models and observations" Peña et al (2016) and a master thesis "Evaluation of obstacle models based on full-scale scanning lidar measurements" Conti et al (2015) are also delivered. In the latter the CFD model and other engineer like models of the fence are evaluated.

IEA Task 27 partners from China are validating their own CFD model of the fence with measurement made available by DTU.

DTU has also contributed to WP4 Micrositing of small wind turbines. The IEA Task 27 activities (fence experiment and model evaluations) were also valuable inputs for a parallel project, "OnlineWAsP" for which an online platform for siting of small wind turbines is now commercially available at http://www.mywindturbine.com/. The mywindturbine.com platform was introduced to IEA Task 27 partners in occasion of the virtual meetings (video-calling) on dates January 2016 and April 2016.

The Recommended Practice on micro-siting of small turbines in highly turbulent sites (WP4) is still incomplete at this time of the project. Input from Denmark is at present under preparation.

DTU Wind Energy participated to the IEA Task 27 committee meetings, presenting status and a market report of the small wind industry development in Denmark.

1.6 Utilization of project results

Recommended practice of IEA Task 27

The work conducted by DTU Wind Energy has contributed to "recommended practices for wind turbine testing and evaluation "12. CONSUMER LABEL FOR SMALL WIND TURBINES. 1. EDITION 2011", ref /6/. And also to the proposal under preparation: "Installation of SWT in the built environments". These documents summarize the best knowledge at the time of writing and shall be treated as recommendations and not as binding standards. Furthermore these documents have served as important work for the development of international standards such as IEC.

Online WAsP/MyWindTurbine.com

The measurement campaign conducted through the IEA Task 27 project has been also used for evaluation of flow models predicting the influence of obstacles on the local wind resources. Engineering like-models including the Wind Atlas Analysis Application Program (WAsP obstacle model) and Computation Fluid Dynamic model (CFD) are evaluated and relative uncertainties are estimated. The results of these studies, ref./4-5/, are used for the development of mywindturbine.com, an online commercial platform for siting of small wind turbines. The mywindturbine.com is the result of a EUDP project "Online WAsP".

Measurements accessible for the scientific community

A journal paper regarding the experiment has been published /1/ and the statistics of the measurement campaign are available at the DTU website.
www.fence.vindenergi.dtu.dk. The purpose is to allow and facilitate the scientific community to access the fence experiment details and measurements in order to evaluate their own flow models.

1.7 Project conclusion and perspective

The IEA task 27 project is delayed and will continue through 2016 and into 2017. The 2016-fall meeting in Denmark is not included in this final report under EUDP.

DTU Wind Energy has contributed to WP3 and WP4 including the following tasks:
WP3: Collection of "new" wind resource and turbine power performance from rooftop /complex terrain test sites

- 3.1 Develop International team
- 3.2 Design the experiment
- 3.3 Define and implement measurement

WP4: Recommended Practice

- 4.1 Micro-siting of small wind turbines

An important contribution to the work is the fence experiment, including a journal paper regarding the experiment has been published, ref /1/, and the statistics of the measurement campaign are public available at the DTU website.

References

/1/. Peña, A. and Bechmann, A. and Conti, D. and Angelou, N. The fence experiment – full-scale lidar-based shelter observations. 2016.

/2/. Measurement of the fence experiment available at www.fence.vindenergi.dtu.dk

/3/. Small wind turbines. myWindTurbine.com is an easy tool for calculation the feasibility of small and medium sized turbines, www.mywindturbine.com

/4/. Peña, A, Bechmann, A, Conti, D, Angelou, N & Troen, I 2015, Shelter models and observations. DTU Wind Energy. DTU Wind Energy E, no. 00923

/5/. Conti, D. (2015). Evaluation of obstacle models based on full-scale scanning lidar measurements. Master Thesis.

/6/. RECOMMENDED PRACTICES. FOR WIND TURBINE TESTING AND EVALUATION 12. CONSUMER LABEL FOR SMALL WIND TURBINES. 1. EDITION 2011

/7/. www.IEAWind.org (This web-site has been blocked by DTU)

/8./ IEA task 27 uploaded presentations and documents ftp://ftp.ciemat.es/pub/IEA_Wind_Task_27_Files/

/9/. www.small-wind.or; Small Wind World Wind Energy Association