TWEET-IE
Twin Wind tunnels for Energy & the EnvironmenT
INNOVATIONS - EXCELLENCE

Requirements for the Certification & Accreditation of NTUA WT facility

Lead Beneficiary: TU Delft
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WP2

Widening of administration and management capabilities

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History and Changes

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Executive Summary

The aim of the present report is to provide a survey of existing standards related to wind tunnel (WT) facilities or measurement techniques and to review and list the accreditation actions that need to be taken by NTUA in order to certify the WT facility as a whole, or to certify/standardize individual technical services offered to the public that are linked to measurements performed in the WT. Therefore, the report

(a) collects and documents existing international certification standards related to WT measurements that are of interest and within the scope of the two NTUA labs involved in the operation of the WT and
(b) outlines the requirements for WT facilities and specific services to comply with the above standards.

Targeted services should fall within the areas of Wind Energy and Environmental/Urban flows which form the backbone of the TWEET-IE activities. The information provided in the report is a result of the work performed under Task 2.2 of TWEET-IE project by WG-CA which consists of experts from all partners (the Leading partners and NTUA representatives). D2.3 prepares the ground for follow up actions to be taken by NTUA in the direction of standardizing some of the services that WT provides to the industry and for ultimately creating the sustainability plan of the WT facility. It is noted that according to the work program, only preparation of such actions is planned within the duration of TWEET-IE project. Preparatory steps that serve the scope of a future accreditation already taken by NTUA are: i) the establishment of a Management Unit responsible for the WT [1], ii) the inventory of the status of the WT tunnel facility in terms of human and material resources and equipment, iii) the benchmarking activities undertaken under the various TWTs. The information collected in the present report is considered as material of major importance for improving the management and technical competence and capacity of the facility and it is envisaged to serve as reference for successfully putting through future accreditation actions.

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1. Targeted services

Early in the discussions with the Leading partners was made explicit that there is no relevant international standard (ISO or equivalent) that specifically addresses WT facilities. This was made clear not only through the discussions within WG-CA but also in the round table discussions that took place during the GOE meeting. Furthermore, none of the Leading Partners WTs (POLIMI, TUM, KIT, TU DELFT) involved in the TWEET-IE project have certified their WT services. This has never been a bottleneck in their collaboration with industrial partners because:

a) industrial collaborators are usually addressed to universities for solving scientifically challenging problems and for performing unique case specific measurements which are impossible to have been standardized in advance,
b) of their established reputation and long-standing experience in wind tunnel measurements.

However, review of existing standards by the WG-CA indicated that there are a number of services related to WT measurements that can be accredited. Such a service that is of great interest to both labs of NTUA involved in the management/operation of the WT facility is the "**WT cup anemometer calibration procedure"** which is addressed by the IEC 61400-12-1/Annex F standard [2]. Furthermore, in connection to the above certified activity and to the corresponding IEC standard (but also to other activities associated with field wind energy related measurements, which are outside the scope of NTUA) an international network called MEASNET has been established by world class public laboratories and companies that provide quality measurements in the field of wind energy. Being a MEASNET member ensures the quality of the provided services, as the network itself evaluates its new members and periodically performs mutual quality assessment activities in which all registered members participate. The requirements and the steps for participating in MEASNET network are detailed in section 4 of the present report.

Furthermore, literature review by the WG-CA indicated that there are several international guidelines related to **atmospheric boundary layer and urban flow** measurements e.g. [3],[4],[5]. These are released by independent standardization bodies but they are not explicitly assessed. However, complying as much as possible with the above guidelines is an assurance for the fidelity of the conducted campaigns. Some of these guidelines are listed and detailed in section 5 of the present report.

Finally, although no international standard exists for the certification of WTs as a whole, there is an ISO/IEC standard (ISO/IEC 17025:2017(E), [6]) that enables laboratories to demonstrate that they operate competently and generate valid results, thereby promoting confidence in their work both nationally and worldwide. Complying with the above standard is a prerequisite for participating in networks such as MEASNET and therefore being first certified in accordance with this standard is considered as an important first step. The main steps for acquiring ISO/IEC 17025(E) certificate are listed in section 3 of the present report.

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2. ISO/IEC 17025:2017(E)

The ISO/IEC 17025:2017(E) document has been compiled with the objective of promoting confidence in the operation of laboratories. This document contains requirements for laboratories to enable them to demonstrate they operate competently, and are able to generate valid results. It requires the laboratory to plan and implement actions to address risks and opportunities. Addressing both risks and opportunities establishes a basis for increasing the effectiveness of the management system, achieving improved results and preventing negative effects. The laboratory is responsible for deciding which risks and opportunities need to be addressed.

In the sequel, the main provisions of the ISO/IEC 17025:2017(E) document are summarized and reviewed. The ISO/IEC 17025:2017(E) document provides:

1) Requirements for ensuring impartiality and confidentiality of the lab.

The standard sets some general requirements regarding the impartiality of the laboratory activities, which shall remain free from commercial and financial interests that would compromise impartiality. Furthermore, the standard requires that the lab sets up an ongoing procedure for assessing possible future impartiality risks.

The standard sets the requirement that the laboratory shall be responsible, through legally enforceable commitments (e.g. non-disclosure agreement), for the management of all information obtained or created during the performance of laboratory activities. Furthermore, personnel, including any committee members, contractors, personnel of external bodies, or individuals acting on the laboratory's behalf, shall keep confidential all information obtained or created during the performance of laboratory activities, except as required by law.

NTUA administration maintains a well-organized contracts and legal department that handles all legal matters with big industrial partners/collaborators including the signing of non-disclosure agreements. Furthermore, NTUA is a non-profit public institution which therefore remains un-biased by commercial interests.

2) Structural requirements for the lab

According to the standard

- the laboratory shall be a legal entity, or a defined part of a legal entity, that is legally responsible for its laboratory activities
- the laboratory shall identify management that has overall responsibility for the laboratory
- the laboratory shall define and document the range of laboratory activities for which it conforms with this document
- the laboratory shall have personnel who, irrespective of other responsibilities, have the authority and resources needed to carry out their duties
- laboratory management shall ensure that communication takes place regarding the effectiveness of the management system and the importance of meeting customers' and other requirements; the

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integrity of the management system is maintained when changes to the management system are planned and implemented

Since there are two labs currently active in the use of the WT facility (Lab. Of Aerodynamics and Lab. Of Innovative Environmental Technologies), both are involved in the management of the WT facility through the established independent management unit which is part of the legal entity of the "National Technical University of Athens (NTUA)". Furthermore, the labs themselves participating in the management of the WT facility are formally founded labs, named as such in the organization plan of NTUA. Both labs have directors who are appointed on the basis of the provisions of the legislation for high education institutes and they also have an approved operation statute.

3) Human – Material – Equipment resources requirements for the lab

According to the standard, as a general requirement the laboratory shall have available the personnel, facilities, equipment, systems and support services necessary to manage and perform its laboratory activities.

Personnel – Human Resources

- Impartiality requirements are binding also for the personnel
- Personnel must be competent in accordance with the lab's management system (competence requirements shall be well documented for all necessary positions/functions along with the requirements for education, qualification, training, technical knowledge, skills and experience)
- The laboratory shall ensure that the personnel have the competence to perform laboratory activities and communicate to them their duties, authorization and responsibilities.
- The laboratory shall have procedure(s) and retain records for determining the competence requirements; selection, training, supervision, authorization, monitoring of the competence of personnel.
- The laboratory shall authorize personnel to perform specific laboratory activities

Facilities and environmental conditions

- The facilities and environmental conditions shall be suitable for the laboratory activities and shall not adversely affect the validity of the results. In addition they shall be neatly documented.
- The laboratory shall monitor, control and record environmental conditions
- Measures to control facilities shall be implemented, monitored and periodically reviewed.

Equipment

Several requirements are set by the standard concerning the equipment used in laboratory activities, the most important being:

- The laboratory shall have access to equipment (including, but not limited to, measuring instruments, software, measurement standards, reference materials, reference data, reagents, consumables or auxiliary apparatus) that is required for the correct performance of laboratory activities and that can influence the results.
- The laboratory shall have a procedure for handling, transport, storage, use and planned maintenance of equipment in order to ensure proper functioning and to prevent contamination or deterioration.

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- The equipment used for measurement shall be capable of achieving the measurement accuracy and/or measurement uncertainty required to provide a valid result
- Measuring equipment shall be properly calibrated. The laboratory shall establish a calibration program, which shall be reviewed and adjusted as necessary in order to maintain confidence in the status of calibration.
- Records shall be retained for equipment which can influence laboratory activities which includes: the identity of equipment, including software and firmware version; the manufacturer's name, type identification, and serial number or other unique identification etc.

Metrological traceability

The laboratory shall establish and maintain metrological traceability of its measurement results by means of a documented unbroken chain of calibrations, each contributing to the measurement uncertainty, linking them to an appropriate reference

Externally provided products and services

The laboratory shall ensure that only suitable externally provided products and services that affect laboratory activities are used

NTUA's staff consists of high quality scientists (all faculty members and most of researchers are PhD holders) and experienced technicians. Moreover, the two labs involved in the management and operation of the WT facility have at their disposal high quality measuring equipment. WT facility's equipment is regularly calibrated and the labs of the WT facility have in their possession official calibration certificates. Some preparatory work in surveying the personnel employed in the WT facility and the available material and equipment resources has been performed under Tasks 1.2 and 2.2 of TWEET-IE project and the results are documented in Deliverables D1.1 [9] and D2.2 [10]. This material will facilitate any certification action that may be initiated within the following years.

Among the various requirements set by the standard, the WG-CA concluded that the only one that requires substantial amount of effort to be fulfilled is the **metrological traceability** requirement. Moreover, it incurs significant cost which should be paid not only once but regularly.

4) Processing requirements

The standard provides detailed requirements concerning:

- the reviewing of requests, tenders and contracts
- the selection, verification and validation of methods
- the sampling of data
- the handling of test data or calibration items
- the compilation of technical records
- the evaluation of measurement uncertainty
- measures for ensuring the validity of results
- the reporting of the results
- the handling of complaints by the customers
- the treatment of work that does not conform to the lab procedures

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- the control of data and information management

5) Management system requirements

The laboratory shall establish, document, implement and maintain a management system that is capable of supporting and demonstrating the consistent achievement of the requirements of this document and assuring the quality of the laboratory results.

In addition to meeting the requirements described in the above sub-sections 1-4, the laboratory shall implement a management system in accordance with Option A or Option B detailed below:

<u>Option A</u>

As a minimum, the management system of the laboratory shall address the following:

- management system documentation;
- control of management system documents;
- control of records;
- actions to address risks and opportunities;
- improvement;
- corrective actions;
- internal audits;
- management reviews.

<u>Option B</u>

A laboratory that has established and maintains a management system, in accordance with the requirements of ISO 9001, and that is capable of supporting and demonstrating the consistent fulfillment of the requirements described in the above sub-sections 1-4, also fulfills at least the intent of the management system requirements of option A (see above).

3. WT cup anemometer calibration procedure – Participation in MEASNET

MEASNET is a co-operation of institutes/companies which are engaged in the field of wind energy and want to ensure high quality measurements, uniform interpretation of standards and recommendations as well as interchangeability of results. The members established an organizational structure for MEASNET and perform mutual and periodical quality assessments for their harmonized measurements and evaluations. The highest tier is the Council of Members which decides on all substantial questions. An Executive Board, composed of three representatives from different members executes the tasks delegated by the Council of Members. Several Expert Groups, specializing in certain measurement tasks, advise and support the Executive Board and the Council of Members on the definition of the measurement procedures. Assessment Teams are established to perform assessments for the admission of new members and for the periodical quality confirmations of MEASNET members. A prerequisite for an entity to become a member of the MEASNET network is to be accredited by ISO/IEC 17025 for the MEASNET approved measurements.

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For much of the last decade, the most reputable European wind test centres have been involved in developing measurement standards to ensure that measurements are performed to a high quality. Over the same period, several national and international recommendations, standards and requirements for measurement procedures for wind velocity and wind turbine generator systems have been developed or are still under development. Consequently, for certain measurements, several different formal procedures for gathering and evaluating the data exist and lead to different measurement results. Experience also showed that measurements, performed by different institutes did not lead to comparable results, even if they took into account the same recommendations.

To improve this situation, in 1997**,** the most experienced wind energy institutes decided to work together in a Measuring Network of Wind Energy Institutes called MEASNET**,** with the goal to work out rules and requirements which will guarantee that high quality measurements are carried out by them**.**

One of the testing activities offered by the MEASNET network which is of great interest to NTUA and to the WT facility is the calibration of cup anemometers. For this particular activity, the MEASNET network follows the provisions and procedures of the IEC 61400-12-1/ Annex F [2].

3.1. WT cup anemometer calibration procedure – Procedures for becoming a MEASNET member

To become a member of MEASNET it is set up as a requirement to participate in an **Applicant Assessment Procedure (AAP)**, which has the aim to ensure that the applicant fulfills the requirements for Members of MEASNET. As mentioned above, the accreditation according IEC/ISO 170025 for **each** service the candidate member applies for. In NTUA's case this would be WT cup anemometer calibration.

The Assessment Plan and Cost Overview (for the assessment) have to be communicated to the Applicant and the Applicant has to agree to both in writing.

The AAP shall be performed for all measurement tasks for which an Applicant might want to be recognized for.

The AAP includes:

- Check against the latest Laboratory Proficiency Testing performed in MEASNET,
- Check of a Measurement Report.
- Visit of the premises of the Applicant, if judged necessary after the check of the measurement report.

The execution of the AAP is under the responsibility of the Coordinator of the respective Expert Group and the process will be checked by the Executive Board appointed for this task by the Council of Members (CoM).

Upon the decision of the MEASNET Executive Board to start the AAP for an Applicant, the Coordinator of the respective Expert group nominates an Assessment Team with a minimum of two and a maximum of

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four members, which are approved by MEASNET for the respective measurement. If necessary the Assessment Team needs a Leader, which is nominated by the Coordinator. The Executive Board has to approve the nominations. The Assessment Team Leader has to come up with an **Assessment Plan**, which can contain all or only some of the actions described by the bullet points above, and an Assessment Cost overview. Both have to be approved by the Executive Board.

The Nomination of the Assessment Team has to be done within 1 month after the request from the Executive Board. After an Assessment Team has been nominated, the Executive Chairman has two weeks' time for the approval; otherwise the Assessment Team is approved. The Executive Chairman will inform the Applicant about the Assessment Team and its Leader.

Within less than one month later the Assessment Coordinator will send the Assessment Plan to the Applicant. The Assessment Plan contains the necessary actions to be undertaken and the Time Schedule. The Applicant can ask for alterations of the time schedule if desired. The Applicant has to react within 2 months from the issue of the Assessment plan. In case the Executive Chairman did not receive any reaction within this period the Assessment Procedure will be stopped. The Executive Chairman will report this refusal to the Applicant.

The Assessment ends with the report of the Assessment Coordinator to the Council of Members.

- If the Assessment was successful, the Assessment Coordinator shall ask the Council of Members for the acceptance of the Applicant for this type of measurement.
- If the Assessment was not successful, the Assessment Coordinator shall ask the Council of Members for the rejection of the Applicant for this type of measurement.

All Assessment reports shall be sent to the Executive Chairman and the Applicant after the Assessment is finished.

3.2. Provisions of IEC 61400-12-1 / Annex F

This section summarizes the main provisions of the IEC 61400-12-1 concerning WT cup anemometers calibration (described in Annex F of the corresponding report [2]).

The annex is divided into 8 subsections (F1-F8) in which the following information is provided:

F1: General requirements

Some general specifications are provided concerning:

i) calibration of the equipment, uncertainty of the calibration, traceability and repeatability of the calibration (to some extend also covered by the ISO/IEC 17025:2017(E)),
ii) the conduction of flow quality measurements at the test station of the WT

F2: Requirements of the wind tunnel

The main wind tunnel requirements are:

- The presence of the anemometer shall not substantially affect the flow field in the wind tunnel.

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- The blockage ratio of the anemometer – defined as the ratio of the anemometer frontal area (including its mounting system) to the total test section area – shall not exceed 0.1 for open test section and 0.05 for closed test section.
- The flow across the area covered by the anemometer shall be uniform. The flow uniformity shall be assessed prior to the anemometer's calibration. Flow uniformity can be estimated using velocity sensing devices, i.e. pitot tubes, hot wires or Laser Doppler Velocimetry and measuring flow profiles in longitudinal, transversal and vertical direction. The flow shall be uniform to 0.2 %. These investigations shall be carried out for the wind tunnel once and additionally after each modification of the wind tunnel aerodynamics.
- the check of the horizontal wind gradient by using two identical pitot tubes. They shall be placed at the exact position where the anemometer will be placed with their heads spanning approximately the area covered by the cup anemometers rotating cups. Then a set of measurements shall be made and the linear regression between the dynamic pressures measured by the two pitot tubes shall be calculated. The difference shall be less than 0.2 %.
- The axial turbulence intensity at the anemometer's position shall be below 2%.
- The wind tunnel calibration factor, which gives the relation between the conditions at the reference measurement position and those at the anemometer position, shall be appraised using pitot tubes.

F3: Instrumentation and calibration set-up requirements

The main instrumentation and calibrations requirements are:

- Dedicated external signal conditioning equipment such as frequency to voltage converters, etc. shall be calibrated in isolation from the anemometer.
- The resolution of the data acquisition system shall be at least 0.02 m/s. Care shall also be exercised in the case of an analogue voltage instrument, to ensure that the signal is adequately buffered to prevent its attenuation by low impedance logging equipment.
- During calibration the anemometer shall be mounted on top of a tube in order to minimise flow distortion. This tube shall be of the same dimensions as the one on which the anemometer will be mounted in service in the free atmosphere.
- It is important to ensure that the anemometer is not influenced by the presence of any reference wind speed measurement equipment. Conversely, the presence of the anemometer shall not affect the flow in the region of the reference instrument.
- The pitot tubes shall be positioned at the test section perpendicular to the flow field of the wind tunnel as accurate as possible. The maximum declination allowed is 1°. The anemometer shall be positioned at the test section perpendicular to the flow field of the wind tunnel as accurate as possible. The maximum deviation allowed is 1°.
- During calibration, the anemometer output signal shall be examined to ensure that it is not subjected to interference or noise.

F4: Calibration procedure

In summary, the main requirements for the calibration procedure are:

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- the anemometer shall run in for about 5 min before the calibration procedure begins in order to avoid the effect that large temperature variations may have on the mechanical friction of the anemometer bearings.
- calibration shall be performed under both rising and falling wind speed in the range of 4 m/s to 16 m/s at a calibration interval of 1m/s or less.
- the sampling frequency shall be at least 1 Hz and the sampling interval at least 30 s. This time shall be increased when low resolution anemometers are calibrated.
- It is important to ensure that anemometer and reference wind speed readings span the same period of time.
- Before collecting data at each wind speed, adequate time shall be allowed for stable flow conditions to become established. This will typically take 1 min, but will vary from facility to facility.
- Stability can be assumed if two successive 30 s means are within 0.05 m/s of each other.

Air density shall be calculated on the basis of the mean wind tunnel air temperature, relative humidity and barometric pressure. The standard provides an adequate formula for the calculation of the air density, based on the above information.

The blockage correction factor for the cases of enclosed wind tunnels should be calculated using Maskell's theorem. If no blockage correction factor is calculated, then about 1/4 of the blockage ratio shall be used for the uncertainty calculation for closed wind tunnels and 1/16 for open wind tunnels.

F5: Data analysis

A linear regression analysis on the calibration data is proposed for the estimation of the major parameters: Offset, slope, regression coefficient, standard uncertainty in the slope and intercept and the covariance of the slope and intercept of the wind speed.

The wind speed values shall be regressed upon the anemometer outputs and not on wind speeds.

F6: Uncertainty analysis

It is important to identify the uncertainty with which the horizontal wind speed incident upon the anemometer is known. It is required that an uncertainty analysis is carried out in accordance with the ISO guide to the expression of uncertainty comprising both type A and type B uncertainty. The magnitude of the net uncertainty shall be assessed statistically and shall take account of:

- flow speed measurement uncertainty (pitot tubes, transducers, air density evaluation, etc.);

- frequency measurements;

- wind tunnel calibration including blockage effect;

- flow variability in the vicinity of the anemometer.

F7: Reporting format

The relevant documentation shall provide information on the procedure followed and the facility used for calibrating the anemometers (test report on the calibration campaign) and on the individual anemometer calibration (anemometer calibration report).

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A list of minimum requirements for the test and calibration report are provided in the document of the standard.

F8: Example uncertainty calculation

A detailed example for the calculation of the uncertainty is provided in the standard.

Based on the specifications of the IEC 61400-12-1, cup anemometer calibration activities can only be conducted in the small test section of NTUA WT. This is because the large section, although satisfies the requirement of the maximum turbulence level, it falls short with regard to the requirement of the maximum flow speed which is 12m/s < 16m/s.

4. Boundary layer measurements

Guidelines concerning the effective modeling of the atmospheric boundary layer in a wind tunnel environment as well as the modeling of atmospheric flows (flows around buildings and other structures, pollutant dispersion measurements etc.) have been released by many organizations globally (VDI-Germany [3], AWES – Australia [4], NIST-US [5], ASCE – US [7], [8]). However, none of them has been shaped yet into a form of a binding European standard. The provisions of the German guideline [3] are outlined in the following. This is the only European guideline that was traced through the literature review performed by WG-CA. Further details into modeling of the wind, pedestrian comfort issues, local and building level wind loads, aeroelastic simulations, instrumentation and quality assurance can be found in [7], [8], which are valuable guidelines for studies on or around buildings and other structures.

The draft of a revised VDI (Verein Deutscher Ingenieure) guideline has been subject to public scrutiny after announcement in the federal gazette. In the Commission on Air Pollution Prevention of VDI and DIN – Standards Committee (KRdL) experts from science, industry and administration, acting on their own responsibility, establish VDI guidelines and DIN Standards in the field of environmental protection. These describe the state of the art in science and technology in the Federal Republic of Germany and serve as a decision-making aid in the preparatory stages of legislation and application of legal regulations and ordinances.

The guideline begins with some important definitions concerning:

1) Atmospheric wind boundary layer: mean profile, turbulence characteristics, full scale data.
2) Similarity laws and requirements (between full scale and WT model) concerning: mean profile similarity, scaling of turbulence, relevant dimensionless dynamic similarity numbers and geometric similarity rules that need to be satisfied by a physically consistent modeling

The guideline continues with the description of the requirements to be fulfilled by the model experiment. As a general guideline it is stated that strict compliance with the similarity laws means perfect geometrical and dynamical similarity in the model experiment. However, for specific problems or conditions of the model experiment the guideline acknowledges that some characteristic numbers cannot, or need not, be fully observed/satisfied. Therefore, for the purpose of quality assurance in model experiments, the reliability and quality of the results has to be documented in any case.

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The documentation of the experiment shall include information on the technique used for the model experiments. It is recommended to record the measurement methods applied, as well as the temporal and spatial resolutions of the measurement instrumentation used, which are relevant with respect to the requirements of the model experiment or measurement. If the measuring system requires calibration, the reference standard (etalon) used, the actual calibration accuracy and the actual reproducibility of the calibration should be stated.

Then specific requirements are prescribed concerning:

- Generation of the boundary layer
- Wind field and dispersion
- Transfer functions and evaluation of the data

4.1. Generation of boundary layer

The model boundary layer established in the model experiment should be documented so as to ensure a physically unambiguous characterization. It should be evaluated by comparison with specified values obtained from natural situations, or from similar wind tunnel boundary layers (this an activity already supported by the TWTs planned in TWEET-IE project). The model boundary layer may be evaluated directly on the basis of a comparison of the parameters of the measured boundary layer, or indirectly by evaluating the boundary layer influence in an idealized dispersion experiment (for example an iso-kinetically emitting point source above the ground). The reliability of the model-experiment results should at least be documented in terms of the reproducibility of the obtained results as determined by repeated measurements under identical boundary conditions of the experiment. If the model experiment yields to results deduced from several individual values, or which are scaled using individual values, the reproducibility of the individual measured values should also be documented. A complete documentation of model-experiment results should include information on systematic errors (bias) of the measurement technique used.

Wind tunnels with a sufficiently long approach flow section are particularly suitable for generating a boundary layer. They allow generating a turbulent boundary layer over roughness elements with scaled-down roughness length. Because of the limited length of the approach flow section, additional fittings, such as sills and/or mixing devices, turbulence grids, and eddy generators are required at the upstream end of the approach flow section. The simulated boundary layers shall comply with the general requirements/definitions provided in the beginning of the guideline (with respect to the time-averaged velocities as well as the turbulence structures of the atmospheric wind flow).

In cases where only the lower part of the boundary layer is simulated, flow similarity within the test section (without the model) should be ensured by verifying the values of the following three parameters:

a) the time-averaged velocity profiles (u/u_{ref}) at the beginning and end of the test section. By fitting the measured values to the analytical expression of the power law and/or the logarithmic law, characterization of the simulated boundary layer is achieved based on Table 1.

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Table 1 Roughness lengths, profile exponents and zero plane displacements [3] characterizing terrain types.

Roughness class	slightly rough	moderately rough	rough	very rough
Type of terrain z_0 in m α	ice, snow, water surface 10^{-5} bis $5 \cdot 10^{-3}$ 0.08 bis 0.12	grassland, farmland $5 \cdot 10^{-3}$ bis 10^{-1} 0.12 bis 0.18	park, suburban area 0.1 bis 0.5 0.18 to 0.24	forest, inner-city area 0.5 to 2 0.24 to 0.40
d_0 in m	≈ 0	≈ 0	≈ $0.75 \cdot h$	≈ $0.75 \cdot h$

h is the mean height of vegetation and buildings, in m

b) the turbulence-intensity profiles (at least I_u), calculated from the standard deviation of turbulence fluctuations σ_u, σ_v, σ_w. Complementing the velocity profiles, turbulence intensity profiles can be compared to those of Figure 1

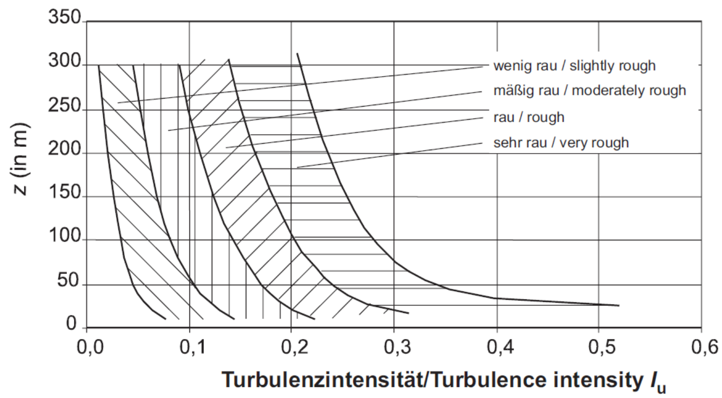

Figure 1 Turbulence intensity profiles characteristic of terrain types [3]

c) the spectral density distribution of turbulence S_{uu} up to an height of several – at least three – times the mean building height. The tallest building should not exceed half of the boundary layer thickness, or half of the test section height respectively.

$$\left[\frac{\bar{u}(z)}{u_{\text{ref}}}\right]_{\text{Model}} = \left[\frac{\bar{u}(z)}{u_{\text{ref}}}\right]_{\text{Full sc}}$$

$$\left[\frac{\sigma_i(z)}{\bar{u}(z)}\right]_{\text{Model}} = \left[\frac{\sigma_i(z)}{\bar{u}(z)}\right]_{\text{Full sc}}$$

$$\left[\frac{f \cdot S_{uu}(f, z)}{\sigma_u^2(z)}\right]_{\text{Model}} = \left[\frac{f \cdot S_{uu}(f, z)}{\sigma_u^2(z)}\right]_{\text{Full sc}}$$

In order for the similarity criteria to apply, further requirements must be met concerning minimum roughness Reynolds number

$$Re_* = \frac{u_* \cdot z_0}{\nu} > 5$$

and the pressure gradient along the test section

$$\frac{\left(\frac{\partial p}{\partial x} \cdot \delta\right)}{\left(\frac{\rho_a}{2} \cdot u_\delta^2\right)} \leq 0.05$$

where (δ) is the boundary layer height and u_δ the mean velocity at that height.

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4.2. Wind-field and dispersion

Modeling flow around an obstacle

The guideline acknowledges that it is rather difficult to achieve Reynolds number similarity for the flow around an obstacle. However, it acknowledges that for sharp edged obstacles, an acceptable minimum Reynolds number that should be attained in the wind tunnel test is 10000. This allows for the assumption of Reynolds number independence. It is also stated that from experience, buildings without any edges such as regular cylinders, require higher Reynolds numbers. In this case, proof shall be furnished that the simulated flow around the obstacle is equivalent to the full scale situation. This can be achieved, e. g., by isokinetic release of a tracer gas from a point source and verification of a constant value of the dimensionless concentration coefficient at various Reynolds numbers.

Blockage

With regard to the blockage effect, the guideline specifies that it must be ensured that the distance between the simulation area and the borders is sufficient and that blockage coefficient remains below case specific limits i.e. <5% for closed test sections and <15% for open test sections.

Modelling of the emission

In a wind-tunnel experiment, the air constituent under investigation is simulated by means of an appropriate tracer. If necessary, the tracer is mixed with air and other inert gases before being released. The conservation of mass has to be checked. Where jets are released, the velocity distribution across the outlet cross section should be uniform. This is true for a tube when the critical Reynolds number in the model is < 2300.

The uniformity of the emission is to be verified by experimental means. Special precautions shall be taken to avoid the influence of external pressure fluctuations on the release from a line source, caused by, e.g., influencing buildings along the source

4.3. Transfer functions

The guideline specifies that the results of the flow and concentration measurements can be transferred to the situation encountered in nature by means of transfer functions. By the term “transfer functions” the guideline implies a set of non-dimensional parameters/quantities that are specifically defined in the text and applied in order to “transfer” the measurement results from the model scale to the full (nature) scale. For velocity measurements:

$$\Psi_{\text{Model}} = \Psi_{\text{Full scale}} \qquad \text{where} \qquad \Psi = \frac{u}{u_{\text{ref}}}$$

and for measurements where frequencies/time scales are of interest:

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$$\left[\frac{t \cdot u_{\mathrm{ref}}}{L_{\mathrm{ref}}}\right]_{\mathrm{Model}} = \left[\frac{t \cdot u_{\mathrm{ref}}}{L_{\mathrm{ref}}}\right]_{\mathrm{Full\ scale}}$$

where (L_{ref}), (u_{ref}) are reference length and velocity scales at either model or natural (full) scale. It is noted that since perfect Reynolds similarity usually cannot be achieved (and the minimum Re number criteria is adhered to), the maximum bandwidth of the time scale is limited by the frequency range represented in the spectrum. The time scales in the wind tunnel experiment are, therefore, limited according to the frequency range represented i.e. measured.

4.4. Evaluation data

Based on data given in the literature, as well as on unpublished results, data for the evaluation of the physical modelling technique are compiled by the guideline. The reference data are limited to the approach flow over rough terrain. Data records are given for the flow field around a cubical building, and for the dispersion of air contaminants released from

• isokinetic-release point sources free from, or subject to, building-related effects, and from

• line sources

Appropriate data records shall be used for other fundamental-flow systems.

4.5. Other guidelines and standards

Although emphasis has been given on the major European standard available [3], it should be acknowledged that it is in agreement with other guidelines and standards, e.g. [7]. Some of the other guidelines, however, provide more detailed theoretical background [8] on the above mentioned criteria and/or the instrumentation details that may be relevant [7].

5. Conclusions

This report outlines existing standards and guidelines related to activities that are considered relevant to the overall scope of NTUA's WT facility but also to the framework upon which the TWEET-IE project was designed (activities related to Wind Energy applications and Environmental and Urban flows). In particular two standards/guidelines are discussed i) one concerning the calibration of wind cup anemometers and ii) a second concerning boundary layer modeling, flow measurements around buildings and pollutant dispersion measurements. In addition to the above, the requirements of a general ISO/IEC accreditation framework regulating and standardizing the operation of labs are discussed.

The main conclusion of the WG-CA is that for the wind cup anemometer calibration procedure (ISO/IEC 17025:2017(E)), most of the requirements set by the standards are already fulfilled by NTUA WT facility:

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- The legal and structural requirements of the lab entities involved in WT work
- Human and material resources required, including the specifications of the facility itself
- Calibration requirements

However, there are certain aspects that are not yet addressed but can be addressed with minimum effort, even during the TWEET-IE project:

- organization of the management system of the facility

The most challenging task is that of ensuring metrological traceability of the measurement systems and equipment. This is a costly and time consuming task that must be maintained on a regular basis. It will be an issue to be dealt with during the writing of the sustainability plan of the facility.

In terms of the guidelines for simulating atmospheric boundary layers in the wind tunnel test section, steps have already been taken and a moderately rough (at the lower limit of rough) suburban (to urban) ABL is replicated. This has already been put forth during the first Twin Test at KIT and NTUA where the simulated boundary layer profiles were compared and benchmarked against the criteria put forth in the VDI standard [3]. Future steps will include replication of smooth to moderately rough (rural) terrains as well as rough (urban) terrains. Efforts have already been put forth in the past and will continue.

6. References

[1] TWEET-IE Deliverable 2.1, Inauguration of NTUA WT administration and management unit, January 2023

[2] IEC-61400-12-1, Wind turbines –Part 12-1: Power performance measurements of electricity producing wind turbines, Edition 1.0 2005-12.

[3] VDI-Richtlinien, Environmental meteorology - Physical modelling of flow and dispersion processes in the atmospheric boundary layer - Application of wind tunnels, ICS 13.040.01, December 2000.

[4] AWES, Quality Assurance Manual: Wind Engineering Studies for Buildings, AWES-QAM-1-2019

[5] Simiu, E., Toward a Standard on the Wind Tunnel Method, NIST Technical Note 1655, December 2009

[6] ISO/IEC 17025, General requirements for the competence of testing and calibration laboratories, Third Edition 2017.

[7] Wind Tunnel Studies of Buildings and Structures/ Aerospace Division of the American Society of Civil Engineers (ASCE Manuals and Reports on Engineering Practice No. 67). Published by American Society of Civil Engineers, Virginia, USA, 1999.

[8] Wind tunnel testing for buildings and other structures / American Society of Civil Engineers. (ASCE standard ; ASCE/SEI 49-12). ISBN 978-0-7844-1228-2, Published by American Society of Civil Engineers, Virginia, USA, 2012.

[9] TWEET-IE Deliverable 1.1, SWOT analysis and definition of KPIs for NTUA WT facility assessment, April 2023

[10] TWEET-IE Deliverable 2.2, 1Assessment of human and material resources for NTUA WT facility – gender balance dimension, October 2023

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