COST 727 – Report from Phase 1

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***Abstract*— The European Cooperation in the Field of Scientific and Technical Research, COST, established an Action on measuring and forecasting of atmospheric icing on structures in 2004 [1]. Phase 1 was completed in 2006 with a report describing the state of the art, mainly concerning available data and devices for measuring and observing icing on structures.**

I. Introduction

THE COST Action 727 was presented to IWAIS 2005 [1]. Several governmental and private institutions participate from 12 European countries: Austria, Bulgaria, Czech Republik, Finland, Germany, Hungary, Norway, Slovakia, Spain, Sweden, Switzerland and United Kingdom. In addition, the Kaganawa Institute of Technology in Japan takes part in the Action. The Action consisted originally of 3 working groups: WG1 "Icing modeling" (chairman: Lasse Makkonen, Finland), WG2 "Measurements and data collection of icing" (chairman: Svein M. Fikke, Norway) and WG3 "Mapping and forecasting of atmospheric icing" (chairman: Hartwig Dobesch, Austria). The chairman of the Action is Bengt Tammelin, Finland. From 2006 WG1 and WG3 merged, and the new combined WG1 is chaired by Lasse Makkonen.

The preparatory phase (Phase 1) terminated in 2006 with a report mainly based of the work of WG2 [2] (can be downloaded from http://www.cost727.org/). This phase focused on state-of-art, mainly to present the status of present and current activities in Europe and other countries concerning ice measurements and data collection of icing. The main content of this report was then to overview such activities in Europe over the last 50 – 60 years, provide links where to find further details on icing data, review available ice detectors in the market, contribute to the set up of icing measurements in Europe to compare and validate various ice detectors, and develop the scientific and technical base of specifications for ice sensors.

COST 727 adopts all definitions and physical descriptions of atmospheric icing and icing processes as specified by ISO-12494 [3].

II. Earlier efforts by international bodies

Many studies related especially to the performance of meteorological instruments under icing conditions have been performed over the last decades. These are mainly performed by various meteorological bodies like the World Meteorological Organization (WMO/CIMO) [4] and the network of European Meteorological services (EUMETNET/SWS I&II) [5], [6]. These studies were supported mainly by France, Switzerland and Finland. The main purpose of these studies was to analyze the performance of ice-free anemometers and other weather sensors under extreme icing conditions. Also the knowledge how to handle data affected by iced-up sensors was improved, and specifications of improved measurements under cold climates and ice affected sites were proposed.

Other studies were performed under wind energy related projects partly supported by European Union: "Wind Energy Production in Cold Climates" (WECO) and "Wind Turbines in Icing Environment: Improvement of Tools for Siting, Certification and Operations" (NEW ICETOOLS") [7], [8]. These studies were important for the planning and operation of wind turbines especially in mountain areas where small ice accretions on the wind turbine blades quickly reduces the efficiency of the turbine. Small or large lumps of ice which are thrown away from the rotating blade can also lead to danger for the public as well as severe damage to nearby structures. It is therefore necessary to have adequate instruments to detect ice accretions at an early stage.

In 2001 the International Energy Agency (IEA) R&D Wind started its Annex XIX "Wind Energy in Cold Climates". The participants have been collecting operational experiences from selected sites that experience frequent atmospheric icing or low temperatures. Collected data include information on performance of standard wind turbines as well as performance of adapted wind turbine technology specifically developed for cold climate sites [9], [10].

The „Conseil International de Grands Réseaux Electriques", Cigre (www.cigre.org), is dealing with all types of electrical component: production, transmission, distribution of electric energy. It is research oriented and organized in study committees. Study Committee B2 WG16 has issued a report on atmospheric icing on electrical overhead lines [11]

The International Electrotechnical Commission, IEC, (www.iec.ch) is the standardization body for all electrical components in parallel to ISO (see below). IEC prepares standards for the design of overhead lines taking into account meteorological parameters such as icing. CENELEC is the European counterpart of IEC [12], [13].

Finally, the report refers to the broad spectrum of papers on atmospheric icing that have been presented to IWAIS since its beginning in 1982.

III. Meteorological measurements under icing conditions

The report notify in particular the limited focus on definitions and standards specified by the World Meteorological Organization (WMO) and its Commission for Instruments and Methods of Observations (CIMO), for both meteorological instruments operating under harsh conditions, and for the observation of icing itself as a particular atmospheric phenomenon with its own fields of interests for the public.

The accuracy of the surface measurements of various meteorological variables is essential for meteorological services, researchers in climatology (e.g. climate change), aeronautical meteorology, etc. It is therefore essential to characterize the effects of ice accretion on the sensors and, when possible, to prevent it.

The following recommendations are stated by WMO/CIMO:

- Improve the quality of meteorological measurements under cold climate conditions,
- Provide manufacturers data for design of ice- free sensors,
- Provide users and providers of meteorological information better bases for selection of suitable sensors for their purposes.

To improve the general knowledge on icing and icing climatology, the following recommendations for further activities are given:

- Improve the design of the instrument (mechanical) and heating system to optimize the required heating power
- Promote the development of icing observation instruments
- Promote the results of past, present and future experiments
- Promote national " icing maps"
- Promote a classification for "meteorological" sensors taking into account accuracy, climatic conditions and reliability of data required for different applications
- Promote the improvement of the WMO/CIMO Guide 8 for measurements in severe icing conditions
- Promote WMO-approved test sites for ice- free sensors, preferably combined with the use of icing wind tunnels for testing of sensors, including anemometers.

The WMO/CIMO is however aware of the mentioned shortcomings and it is the intention of COST 727 to proceed with the collaboration with CIMO in order to further develop this area of meteorological measurements.

ISO 12494 [3] gives a generic definition of atmospheric icing: *"Ice accretion can be defined as any process of ice build up and snow accretion on the surface of an object exposed to the atmosphere"*. In order to advance the specifications and requirements for meteorological instruments and icing sensors of various kinds it is found necessary and practical to introduce two new definitions: 1) Meteorological icing and 2) Instrument icing.

Meteorological icing M_{icing} is defined as "*the duration of a meteorological event or perturbation which causes icing [unit: time]*".

Meteorological icing can be characterized by a) the duration of the icing event and/or b) the meteorological conditions, and possibly with additional information such as: c) the total amount of ice accreted on a standard (reference) object during the icing event, and d) the average and maximum accretion rate.

Automatic certified reference sensors are lacking for the determination of items a) and d), whilst the items b) and c) can be more or less achieved with presently available technology.

However, it must be noted that meteorological icing is not easy to define. It is today widely accepted that it depends on the shape of the object, the wind speed, the air temperature, the liquid water content LWC and the droplet size distribution. The latter two being difficult to measure in operational mode. Tentative developments have been achieved, such as the Rotating Multicylinder RMC. Unfortunately, these cannot be operated in an automatic way and cannot therefore be implemented at automatic stations. New developments may improve this situation.

Instrument icing I_{icing} is defined as ***"the duration of the technical perturbation of the instrument due to icing [unit: time]"***.

Instrument icing is the effect of icing on the quality (e.g. degradation) of the measurements, depending on icing conditions as well as the design of the instrument. It can be today only recorded by analyses of video recordings, and/or regular visual observation, or by comparison of the measurements with a reference that is kept ice free. This definition is valid for all objects or structures. It can be easily generalized to "structural icing".

The **Performance Index PI** of an instrument is the ratio of the instrument icing to the meteorological icing: $PI = I_{icing}/M_{icing}$.

Realising the importance of the local exposure at a certain site, a **Site Icing Index Sn**, is adopted from [5]. Sn varies from S1 to S5 depending on combinations of icing frequency, duration and intensity.

Finally, in order to classify meteorological sensors it was found necessary to introduce an **Instrument Class Index ICI**. The ICI ranges from 1 to 5 as shown in Table 1. The interpretation of the ICIn index is strongly linked to the station's site icing index (Sn, n=1-5) and the effect of icing on the results' quality as described by the PI defined above.

TABLE 1
CLASSIFICATION OF INSTRUMENTS IN TERMS OF MEAN PERFORMANCE DEPENDING ON THE STATION'S SITE ICING INDEX (THE AVAILABILITY VALUES DISPLAYED IN ITALIC ARE PURELY HYPOTHETICAL AND WILL HAVE TO BE SPECIFIED IN FUTURE).

Instrument Class Index	PI for S1-S5	Mean availability in % for S1-S5	Remarks
ICI5	0	*100 %*	Excellent instrument not sensitive to icing
ICI4	0 - 1	*99 - 90 %*	Good instrument, little sensitivity to icing
ICI3	1 - 5	*89 - 70 %*	Instrument moderately sensitive to icing.
ICI2	5 - 20	*69 - 40 %*	Instrument to be used only with separate icing detection
ICI1	20 - ∞	*39 - 0 %*	Instrument not recommended for such applications

IV. EXAMPLES OF EXISTING ICING DATA

Numerous activities in the field of measurement of icing have already taken place in many countries in Europe as well as other parts of the world. An overview of what has been achieved to date is given in a separate chapter including Annexes. This chapter is based on information provided by members of the COST Action 727. Other data may be available in some countries. The following text is an extract of Chapter 6. Further details and references can be found in the report [2].

A. Finland

VTT and Digita (former Finnish Broadcasting Co., Distribution Dept.) have made measurements of icing on tower structures and measurements of drop size and liquid water content of clouds and comparisons of meteorological instruments on hilltops in severe icing conditions in Finland since 1986. An operating 128m tall TV tower and a 7.5 m test tower at Ylläs (700 m asl) have both been equipped with load cells, so that the ice load on them could be continuously measured. Ice detectors were also tested, and VTT has also later performed ice detector tests in four locations during the period 1998 – 2005.

The Luosto test station (500 m asl) in northern Finland was set up during the winter 2000/2001 by Finnish Meteorological Institute. The main purpose of the Luosto test station is to measure icing as well as the behaviour of meteorological instruments.

B. Germany

Icing measurements were carried out at altogether 40 locations in the eastern part of Germany during 1965 – 1990, up to 35 locations were operated simultaneously. Since 1991 five stations are still in operation. A standard observation pole has been used for all stations. On the Deutscher Wetterdienst's meteorological observatory Lindenberg, ice measurements are currently made at 10, 50 and 90 m above ground.

C. Slovak Republic

The Slovak Hydrometeorological Institute has data on icing from 13 stations, ranging from 115 to 2 634 m asl. The measurements are both visual and by instruments. The oldest data are from 1957.

D. Norway

During the period 1978-2000 the Norwegian Power Grid Company, Statnett SF, has operated more than 20 sets of racks for ice measurements in 16 locations in mountainous areas for power line design purposes. Each set consists mainly of two perpendicular racks, where one leg is perpendicular to the main icing wind direction. Some sets were established to study the effect of local topography. Most of these racks are in coastal mountains in the range of 600 – 1 200 m asl.

A measuring station for ice monitoring has been operated at a coastal mountain of about 800 m asl in central western Norway with the support of the Norwegian Research Council and two Norwegian energy companies. The station was equipped with ice-free wind sensors, temperature sensors and a web-camera. Ice accumulation was derived from web-camera pictures of wires. Measurements took place during two winters.

E. Czech Republic

Two institutes have performed icing studies in Czech Republic, EGU Brno and Institute of Atmospheric Physics (IPA, Prague). EGU Brno has operated a test site on Studnice (800 m asl) continuously since 1940. Ice loads were measured on a rack with orthogonal rods 2 m above ground. This unique time series is outstanding, since it is the only series of this kind in the world covering such a long time period.

EGU Brno has developed the instrument "METEO" which is installed at 14 locations in the country. The measuring probe is a vertical rod of 30 mm diameter.

IPA has a similar instrument, IceMeter, installed in two locations, Milesovka (837 m asl) and Nová Ves.

F. UK

Test data on icing has been available on rotating rigs and test spans since 1988. Many of these sites lasted only a few years before being closed down for financial reasons. The longest running site, at Deadwater Fell in Northern England, was established in 1991 and is still currently open, although there is no continuous ice measurement over this period. It currently monitors wind speed and direction, temperature, ice loads (by time lapse video cameras and also load cells), precipitation and relative humidity. It has operated the Gerber instruments on loan from the UK Meteorological Office. Measurements have been made on conductors from 16mm² to 800mm² of the copper, aluminium and covered variety as well as fiber optic systems such as Optical Pipe Ground Wire (OPGW), fiber-wrap and All Dielectric Self-Supporting (ADSS).

G. Sweden

Three different sensors (IceMonitor, HoloOptics and Segerstrom) are currently being tested under field conditions in Sweden and Norway. Meteorological parameters are measured, along with icing data, in Ritsem, Åre and Drammen (Norway).

H. Bulgaria

The initial icing observations in Bulgaria started in the late 50-s and in the beginning of the 60-s in some stations of the meteorological institute. The stations were chosen to cover the territory of the whole country. The ice measurement device was a couple of perpendicular conductors with diameter of 5mm located in the directions N-S and E-W.

I. Hungary

Visual observations of atmospheric icing enable from 1970 till nowadays, carried out by Hungarian Meteorological Service (HMS) and Hungarian Defense Forces (HDF).

J. Other countries

Some information is included also for Russia and Canada, according to input from members of the WG. Unfortunately Iceland is not taking part in the Action and their measurement and data acquisition programs are not included in the COST report.

K. Testing of weather sensors under icing conditions

Meteo-France and MeteoSwiss carried out inter-comparisons of wind instruments at the Mt Aigoual (France) from July 1992 to October 1993. The meteorological performance of the tested sensors was not perfect and does not meet the WMO accuracy recommendations. It appears difficult to be both “accurate” and rugged for severe icing.

The EUMETNET “Severe Weather Sensors” (SWS II) project tested 15 wind sensors, 6 temperature and humidity measurement systems with different types of shields and 4 solar radiation sensors equipped with heating. During the project also different methods of measurement of atmospheric icing were used and tested. The three test sites were located in northern Finland, in the Swiss Alps and close to the Mediterranean in the French mountains, all with more than 60 days/year of atmospheric icing.

From the results it can be seen that heating power is required especially for wind measurements, but the power consumption can be relatively low if the sensors are properly designed. The tests and verifications showed that wind speed, wind direction and air temperature could be measured with high accuracy and high reliability at cold climate sites under most severe icing conditions even at automatic weather stations. For temperature and humidity sensors, some of the shields provide significant improvement in comparison with measurements performed with other systems in use at different national meteorological services. However, under harsh conditions, the reliability of temperature and humidity measurements does not yet reach the level available for wind measurements. Concerning test measurements on the heating/ventilation systems for solar radiation measurements, results show that strong icing conditions may dramatically disturb the measurements. None of the tested systems were able to fully withstand the harsh climatic conditions prevailing at such sites.

It was not possible to study the performance of the various sensors versus intensity of ice accretion due to the lack of dedicated sensors to measure icing.

V. Requirements for ice detectors

A. Concepts

Many sensors that are designed and labelled as ice detectors are available. Some of the instruments measure icing rate, some measure the weight of ice (persistence and maximum loads) and some indicate if an icing event is ongoing. Therefore, the purpose for using ice detectors needs to be defined. Requirements regarding time resolution, measuring range, threshold values as well as response time of sensors depend on the purpose of individual measurements, and are therefore not further specified in the generic descriptions given in the report.

The range of use varies between different ice detectors. For example, some sensors have been designed for aviation purposes and perform well on airplanes, but may not be very well adapted for meteorological purposes due to different environmental conditions. All icing types that adhere on static or moving structures can be harmful and need to be identified.

Definition of the range of use and some calibration scheme might improve the current situation. Range of use and data verification could possibly be carried out in icing wind tunnels, where the icing condition can be regulated and monitored. Kanagawa Institute of Technology (KAIT) has conducted wind tunnel test for investigation of icing events on airfoil models and anemometers.

A further possibility lies in the development and long term operation of “icing test centres” similar to (or included in) the Regional Instruments Centres (RICs) of the WMO where market available and future instruments could be tested under different climatic conditions (e.g. Scandinavia, Alps, Pyrenees, etc.).

B. Siting of icing sensors

ISO 12949 recommends 10m measurement height above ground. However, as icing measurements are dependent on the different application types, ice sensors can be installed at different heights. Automated weather stations are not generally appropriate as they are located close to ground level and seldom provide a correct representation of those icing conditions that prevail at a higher level e.g. wind turbine rotors.

Ice accretion on structures is not only a function of environmental parameters, but is also dependent on the properties of the accreting object itself, e.g.: size, shape, flexibility and orientation relative wind direction, and to some extent surface structure and material.

A **standard reference** device should always be part of the measurements, giving the traceability to standard measurements of ice accretion. Other parts of the set-up may help to establish the connections between “standard accretions” and the most important structural parameters as described above (size, shape, etc.). These extended measurements should only be executed at special selected sites, and collected data should be analyzed and used, generally together with the standard measurements. Frequency of observations may be adjusted to the local conditions.

It is important to add also visual observations during and/or after the accretion period, because only these types of observation can give sufficient information on complex load situations. Visual observations have to be logged, and documented with appropriate digital camera pictures. Remote reading (including camera observations) makes it possible to get online information about an icing event so that the site may be visited in proper time.

C. *Guidance for selecting ice detectors*

Appropriate ice detectors should be chosen with respect to the purpose of their use. There are presently two systems of ice detectors: a) with status icing/no icing, or b) with recording of the whole icing cycle (mass, accretion rate).

The size of the detector probe has a significant effect on performance of an ice detector. When icing detectors shall be selected, the purpose of the measurements has to be considered carefully. For example, smaller droplets in low speed airflow pass large objects more efficiently due to their low inertia and the fact that large objects deflect the airflow upstream from the object (collision efficiency). Therefore, no single ice detector can provide data that are directly applicable to all types of structures and conditions. It is then necessary to select ice detectors according to the applications, such as wind turbines, electric power lines, road safety, airports, railways, cable cars, ski lifts, telecommunication towers, etc.

VI. Availability, verification and requirements for ice detectors

There are presently few available instruments on the market. However, there are some prototype instruments which seem very promising and may lead to interesting products after thorough testing and certification. These instruments are based on different working principles:

a) Vibrating rods: the vibrating frequency depends on the state of the rod (yes/no information)
b) Direct infrared beam backscatter: light is reflected as soon as the sensor’s surface is covered with a film of ice.
c) Infrared beam reflected on surface: the reflection characteristics change when the „mirror“ is covered with ice.
d) Measurement of the weight of ice.
e) Measurements of LWC and droplet size distribution.
f) Detection of the attenuation of ultrasonic signal on ice detector structure due to ice.
g) Detection of changes in the electrical impedance on the surface of the probe.
h) Obstruction of light path.

Table 1 displays the available and prototype instruments, to the best knowledge of the COST-727 / WG2 participants.

Table 1

List of available and prototypes of ice detectors on the market

Type	Instrument	Manufacturer
a	Rosemount 0872J / 0871LH1	Goodrich (USA)
	Rosemount 872C2 (ASOS)	Goodrich (USA)
	SYGIVRE (Icing Rate Meter)	Hydro Quebec – Transénergie (CA)
	Vibrometer (Prototype)	Boschung (CH)
b	Infralytic IR detector (Prototype)	Infralytic (D), MeteoSwiss (CH)
c	T21, T23 and T26	HoloOptics (SE)
d	ICEmeter	IAP (CZ)
	METEO device	EGU (CZ)
	IceMonitor	Combitech (SE)
	ICECylinder (Prototype)	FMI (FI)
	EAG 200	*(D) No longer manufactured*
e	Rotating Multicylinder (Prototype)	VTT (FI), STATNETT (NO)
	Gerber	Gerber Scientific Inc. (USA)
f	Labko LID-3210C	Wavin-Labko (FIN)
g	Instrumar IM101 V2.4	Instrumar Inc. (CA)
h	Jokkmokk	Segerström (SE)
i	IceMeister	www.newavionics.com

The ISO 12494 standard ice collector has been built in one version in Sweden (Combitech: automatic weighting, free rotation) and two in Finland (Digita: automatic weighing, forced rotation and FMI: manual weighting, forced rotation). A further development is presently being designed in Switzerland to yield ISO compatible sensors with automatic weighting and forced rotation (Markasub) within the framework of a national project linked to the COST-727 Action. For the detection of the meteorological icing (see definition above) M_{icing}, there are a few systems which are either available on the market (Rosemount Goodrich), or available as prototypes (HoloOptics, Infralytic, Vibrometer/Boschung, etc.).

The experiences with automatic instruments for ice measurements are summarized in the report. In short, these experiences are that most of the instruments do not perform satisfactorily over the season. Some of the prototypes are still technically insufficient and not feasible for “plug-and-play” use. So far it seems that the Rosemount/Goodrich ice detector and the IceMonitor are most feasible for field application. However, the availability for service of the Rosemount/Goodrich is not as good as it should be and the IceMonitor still has to be improved on some details.

VII. Long term recommendations for ice measurements in Europe

As icing conditions and icing climate vary significantly within Europe it is important to perform the measurements at different parts of Europe, noting the different climatic aspects:

- *Northern European mountains* with long icing periods under wide temperature and humidity range and lack of solar radiation (typically rime ice)
- *Alpine regions* with icing strongly depending on the

altitude (typically rime ice and wet snow)
- *Central and Southern European mountainous* areas with icing and strong sunshine periods causing numerous melting and freezing consecutive events (typically glaze and rime ice)
- *Maritime regions in Western Europe* (typically wet snow)

Consequently, a number (3-6) of test centers should be established and operated in Europe (and in the world). There are however two points of view which will have to be combined in order to fulfill the requirements of the different communities: 1) specification of users and 2) specification of purpose.

The users may be:
- Modelling
- Electrical power lines
- Wind turbines
- Towers and masts
- Road/railway safety networks
- Cable cars and others equipments for tourism purposes
- Airport safety
- Weather forecasters: development and control procedures for models
- Climatologists: maps, long-term representativity and climate change
- Others

To cover the various purposes the following aspects will have to be dealt with:
- 3-6 test sites in Europe covering the different climatic environments (e.g. Luosto, Finland; Guetsch, Switzerland; Mt Aigoual, France; Studnice, Czech Republic; Spain; Germany; UK; etc.)
- 2-3 „reference“ instruments common to all sites: standardized testing and certification procedures and standardized data format
- Flexible infrastructures for the installation of different test beds (e.g. for wind turbine and power line testing)
- Common monitoring and quality control procedures (for future certification)
- Complete high quality data sets for forecasting and climatology.

In relationship with the establishment of icing test centres, a permanent forum for monitoring icing in Europe needs to be established. The proposed way to achieve this goal is to establish projects on the European level.

Appropriate task specifications will be handled within Phase 2 of the present COST-727 Action in relationship with the establishment of the test centres. There are two complimentary activities which will have to be further analyzed:
- Launching of a new EUMETNET and/or EU project for the establishment of long-term icing test and observation sites in Europe
- Integration of icing measurements in meteorological networks under the umbrella of WMO/CIMO

VIII. Acknowledgment

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