FINAL PUBLISHABLE REPORT

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Internal Funded Partners: 1. IMBiH, Bosnia and Herzegovina 2. CMI, Czech Republic 3. FSB, Croatia 4. INRIM, Italy 5. DMDM, Serbia 6. NSAI, Ireland 7. TUBITAK, Turkey 8. UL, Slovenia	External Funded Partners: 9. ME-BoM, North Macedonia 10. MER, Montenegro	Unfunded Partners:
RMG1: JV, Norway (Employing organisation); INRIM, Italy (Guestworking organisation) RMG2: DPM, Albania (Employing organisation); CMI, Czech Republic (Guestworking organisation)		

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1 Overview

The control and measurement of humidity is important for many industrial applications and to ensure the appropriate storage of materials and products. The overall objective of this project was to develop or extend the measurement and research capabilities of the participating emerging NMI/DIs' countries in the field of humidity measurements via the development and characterisation of an inner chamber for calibration of relative humidity instruments and a systematic review and improvement of dew point generators. The extent of improvements was designed to meet stakeholder needs, with an optimised effort to avoid duplication of resources. Individual strategies for humidity metrology development have been prepared by the emerging NMI/DIs and then discussed within the EURAMET community, ensuring a coordinated and optimised approach.

2 Need

Humidity is a vital parameter in the control of indoor climate and ventilation, the storage of food products, industrial and medical gases, textile, paper and many other products. Humidity affects many properties of air, and of materials in contact with air. Water vapour is a key agent in both weather and climate, and it is a key atmospheric greenhouse gas. Air-conditioning systems in buildings often control humidity, and significant energy may go into cooling the air to remove water vapour. Humidity measurements contribute both to achieving correct environmental conditions and to minimising the energy cost of this. A huge variety of manufacturing, storage and testing processes are humidity-critical. Humidity measurements are used wherever there is a need to prevent condensation, corrosion, mould, warping or other spoilage of products. Air humidity is also a crucial parameter due to the enormous heat capacity of gaseous water and its key role in atmospheric processes. Traceable measurements of air humidity from the ground level up to the stratosphere are required. Numerous energy technologies – established and novel – need reliable humidity measurements in a range of gases, at a range of pressures.

Prior to the start of the project, the development of humidity sensors and apparatus had matured to a level where traceable calibration was beneficial to all industries in which humidity and moisture measurement and control are important. Measurement of humidity is complex and vitally important to a huge range of industries, as well as in healthcare and in terms of climate change and global warming.

The NMI/DIs in the consortium often received feedback from their clients, indicating a desire for improved uncertainties in humidity measurement. Due to the tightness of manufacturer's specifications and the difficulty in achieving the uncertainties necessary to verify these specifications, there was an urgent need to improve the uncertainty of relative humidity and dew point measurements in most emerging NMI/DIs.

Establishing the infrastructure for humidity measurements, assuring traceability and providing dissemination are important concepts in both developed and emerging NMI/DIs as well as a precondition to related research, industrial applications and quality standards and support for various services, including the grand challenges (health, environment and energy) and closely associated with quality of life measures and implementation of specific EU legislation.

3 Objectives

The overall objective of this project was to develop or extend the measurement and research capabilities of the participating emerging NMI/DIs' countries in the field of humidity measurements.

The specific scientific and technical objectives of this project were:

1. To identify existing and future needs in the field of humidity measurement in the participating emerging NMI/DIs' countries.
2. To improve measurement methods in the field of humidity via the development and characterisation of an inner chamber for calibration of relative humidity instruments. The target uncertainties are between 0.3 %rh and 2 %rh for a relative humidity range of 2 %rh to 95 %rh at temperatures from -60 °C to 100 °C. To implement the improved relative humidity capability into the national/regional traceability infrastructure.

3. To organise and undertake an intercomparison of relative humidity measurements using the small chamber to underpin and validate the procedures developed and measurement capabilities of the participants.
4. To improve research capacity in the field of dew point measurements by systematic review and improvement of dew point generators. The target uncertainties are between 0.05 °C and 0.1 °C for a temperature range of -70 °C to 90 °C. To implement the improved dewpoint capability into the national/regional traceability infrastructure.
5. To develop individual strategies for the long-term development of research capabilities in humidity traceability including a strategy for offering calibration services from the facilities established to customers in their own country and neighbouring countries, through questionnaires and workshops organised in the local language, which will involve the broadest spectrum of stakeholders. The individual strategies will be discussed within the consortium and will lead to an overall strategy document to be presented to the EURAMET TC-T, to ensure that a coordinated and optimised approach to the development of traceability in this field is developed for Europe as a whole.

4 Results

Objective 1

To identify existing and future needs in the field of humidity measurement in the participating emerging NMI/DIs' countries.

The needs related to relative humidity and dew point measurements in the emerging countries were identified through engagement with the stakeholders. Separate surveys were conducted for identification of the needs with regards to relative humidity measurements and dew point measurements. The surveys were conducted through questionnaires and the data collected was analysed and used as the basis for an assessment of the needs for relative humidity and dew point measurements in the participant's countries. Identified needs were then considered through the rest of the project's activities, including the definition of scope for the training organised for partners and stakeholders in participating countries. Beyond the scope of this project, data obtained through the questionnaires will be useful for planning of the future development activities in partners NMIs/DIs as well as for other national and international projects.

Relative humidity measurements

The questionnaire was prepared by UL, with the help of the project partners. The systematic analysis of required data, identified stakeholders and potential need resulted in a questionnaire with 54 questions, which matches the needs of the NMI/DI in each country, accredited laboratories, industry and any other stakeholder.

With the increased importance of relative humidity measurements in everyday use and critical industrial applications, the importance of traceable measurement equipment increases. As a result, it was decided to perform a survey among NMI/DIs and stakeholders to collect the organizational details and to identify the relative humidity range and types of relative humidity sensors used, the expected temperature range for relative humidity sensors, the type of gases in which relative humidity has to be measured, pressure, gas flow limitations and other important issues.

In total, 40 full responses were received from 9 countries: Bosnia and Herzegovina (3), Croatia (4), Czech Republic (2), Ireland (14), Italy (2), Macedonia (1), Montenegro (3), Serbia (4), Slovenia (5) and Turkey (2), with average interview time of 17 minutes per participant. The majority of answers were given from persons who are directly involved in the relative humidity measurements. Out of 40 answers, 13 were NMI/DIs (32.50 %) and 27 non-NMI/Dis (67.50 %).

All the NMI/DIs already had laboratories for dissemination of relative humidity measurements. Almost all known physical methods are used for the generation of relative humidity: two pressure – two temperature; two pressure – one temperature; climatic chambers; saturated salt solution; chamber immersed into calibration bath, supplied with an air of known dew/frost point (generated by primary dew/frost point humidity generators). There is also a range of climatic chambers from different manufacturers (Thunder Scientific, Weiss, Kottermann, Votsch, Kambič, Binder, Heraeus) used either standalone and/or in combination with reference dew-point or relative humidity meters (MBW, General Eastern, Michell and Rotronic) and/or in combination with a dew point generator. All the countries can perform measurements in the range of relative humidity between 10 % and 90 % r.h. Among them, eight can achieve relative humidity up to 95 % r.h., while two can go below 10 % r.h. The temperature range, at which relative humidity is measured can be divided into three major ranges: room temperature (around 23 °C, four countries), -10 °C to 70 °C (5 countries), and positive temperatures from 0 °C to 60 or 70 °C (4 countries). All the laboratories are performing their measurements in air at atmospheric pressure. Typical calibrated sensors are capacitance hygrometers, with a minority also performing calibration of mechanical relative humidity meters. On average, two staff members are involved in humidity activities in each country. Calibration is provided to other laboratories accredited for relative humidity calibrations, industry and public service. Besides providing traceability in the above mentioned ranges, some of the laboratories are offering training, consulting and product conformity. While 11 laboratories have already participated in interlaboratory comparisons, only one has CMCs published in the BIPM KCDB. Many are waiting for the results of the intercomparison carried out in this project.

Among non-NMI/DIs, answers were received from accredited laboratories, pharmaceutical companies, medical, food production, storage, product validation testing and companies which are monitoring environmental parameters. They are using a broad range of instruments such as capacitive hygrometers, psychrometers and mechanical hygrometers for measurements in the laboratory as well as for on-site measurements. The relative humidity range required is mainly from 10 to 90 % r.h. at temperatures from -25 °C to 90 °C, in air at 1 bar pressure with an uncertainty of 1 % r.h. In general, there are problems with condensation, defining all the uncertainty components, issues at extreme points of r.h. and temperature range, long-term stability of the humidity and sometimes saturation of sensors at higher values of relative humidity. Among the customers from a wide range of industrial, research and public services, the most demanding are measurements in pharmaceutical, food, automotive, storage, cleanrooms, aerospace, biomedical devices and research. Most of the participants would like to have traceability provided within their countries, broader range, and lower measurement uncertainties. The tighter the calibration, the better their measurements and products are. As the main reasons for having a national laboratory for relative humidity dissemination could be summarised as lower cost of transport and customs fees, knowledge transfer, turnaround time, inter-laboratory comparisons, ease of access if required and increased confidence. Around 60 % of answers show that there is a need for training in the field of relative humidity, covering the following topics: estimation of measurement uncertainty of calibration using an air relative humidity meter, a theoretical part that includes h/s diagrams at different ambient pressures, practical experience in different situations and dew point measurements / application of specifications for RH measurements. Theoretical knowledge should also be improved from time to time in relation to new technologies and new demands on the market. In the end, it is clear from the answers and comments, that there is not an adequate calibration guide (EURAMET, or ISO) for air humidity measurement, so our main problem is a lack of knowledge in that field. Writing of such a guide should be part of some future project. For industry, correct and reliable measurements of relative humidity are of extreme importance. Adequate national labs are therefore of great importance for competitiveness and progress as providers of knowledge that is highly appreciated by industry.

Dew point measurements

The questionnaire related to dew point measurements and traceability was prepared by INRIM. As a minimum, the questions covered the temperature range, measurement media and pressures used. INRIM sent the questionnaire to NSAI, DMDM, IMBiH, FSB, CMI, ME-BoM and MER for distribution to stakeholders in their respective countries. The completed questionnaires were returned to INRIM for analysis. Based on information on stakeholders' needs, CMI and INRIM made a list of existing capabilities and future needs of participating countries regarding dew point measurements for sensor calibration. This list was then matched against a table of the current capabilities of DMDM, NSAI, IMBiH, ME-BoM, MER and FSB and weak points and gaps were determined.

In total, 33 responses were received from seven countries, seven from NMIs/DIs and 26 from stakeholders. Unfortunately, most of the answers received were related wrongly to RH measurements. This fact can be explained through a lack of clarity in the questions on the questionnaire, poor communication between NMIs and stakeholders and the fact that majority of the contacted stakeholders work in the field of RH measurements and when contacted, wanted to reply to the questionnaire to support the reference NMIs/DIs. Nevertheless, in situations where the responses to questionnaires were related to RH measurement and the stakeholder stated both the relative humidity and temperature range, the related DP/FP range was calculated, and the response was considered as valid. Many of the stakeholders expressed the requirement for training in DP/FP measurement matters, including the uncertainty calculation. Although most of the stakeholders know their traceability provider, there were some cases where providers were not stated. However, it was also stated that they perform traceable measurements. The contacted stakeholders can be categorised to calibration labs, industry, and public service companies. All stakeholders expressed the requirement of having a dissemination lab for DP/FP measurement in their own country for the same reasons already identified for RH measurements, as mentioned above. When the NMI/DI in the respective country does not meet stakeholder needs, the stakeholders know how to obtain traceability elsewhere. A lot of the contacted stakeholders collaborate with NMIs or DIs, not exclusively in their own country.

Based on the outcome of the questionnaires on the needs regarding relative humidity measurements, dew point measurements and traceability, the first training course for the consortium members and interested parties was prepared and held in Ljubljana on the 24th and 25th January 2017. Afterwards, training and workshops for stakeholders were also organised in Italy, Ireland, Bosnia and Herzegovina, Serbia and Croatia.

Objective 2

To improve measurement methods in the field of humidity via the development and characterization of an inner chamber for calibration of relative humidity instruments. The target uncertainties are between 0.3 %rh and 2 %rh for a relative humidity range of 2 %rh to 95 %rh at temperatures from -60 °C to 100 °C. To implement the improved relative humidity capability into the national/regional traceability infrastructure.

After determining existing capabilities in each member institute, the consortium designed an inner chamber for calibration of relative humidity instruments (new RH chamber), intended for use in combination with the climatic chambers already existing in humidity laboratories. The primary assumption was that the new RH chamber would provide a calibration environment of higher stability and lower temperature gradients in comparison to the existing climatic chambers, leading to an improvement in corresponding calibration uncertainties. As indicated through the surveys, for calibration of RH instruments, laboratories use a wide range of climatic chambers from different producers that are also greatly varying in working volume sizes and dimensions. Amongst only the partners' laboratories, the working volumes of the existing climatic chambers ranged from 24 litres up to 227 litres. Moreover, there are also different calibration methods, different supplies for the air of known dew/frost point temperatures and different reference hygrometers in use. A few of the laboratories already had an inner RH chamber implemented in their measurement setups. However, those chambers were custom made and therefore appropriate for use only in similar climatic chambers, with similar reference and auxiliary measurement equipment and for similar calibration methods. As part of a Researcher Mobility Grant, a researcher from DPM, Albania investigated potential improvements to homogeneity and stability by using a reduced volume within a small chamber, as well as the effect of the reduced volume on different types of RH probes. Going beyond state of the art, the consortium worked on an innovative new design for a universal inner RH chamber, appropriate for use in as many setups and as many methods as possible. To achieve this goal, a modular design was adopted for the new RH chamber. The new RH chamber consists of separate blocks, each able to accommodate one relative humidity probe. As these blocks can be connected, using a connection ring with seals, the user can assemble the chamber for the accommodation of the desired number of relative humidity probes (for example one standard and several under calibration).

Moreover, there are two types of blocks available for chamber assembly, the straight and the elbow with a 90° angle. By their combination, the new RH chamber can be assembled in various shapes, enabling users to choose the one that suits their requirements best. The blocks and adapters are dimensioned for the accommodation of cylindrical probes up to a diameter of 30 mm, which is suitable for the majority of current probes. For users that require the ability for calibration of larger probes, the chamber assembly components should be scaled up (which is relatively easy to do), while retaining the same initial design. Besides the bore for the introduction of RH probes, the adapters also have four additional bores, each with threads appropriate for connection of standard tube fittings, readily available on the market. Those bores are meant for insertion of additional thermometers inside the block's working volume, for connection of a pressure gauge and for introducing or extracting sample gas, although they can be used for any other purpose relevant for the user. As identified through surveys, some laboratories use climatic chambers as a source of sample air of known dew/frost point temperature while the others have the option of using a dew/frost point generator. Therefore, the new RH chamber was designed to fulfil both requirements. When air is supplied directly from the climatic chamber, an additional fan can be mounted to the new RH chamber outlet, enabling the user to establish airflow through it. By using relatively simple electronic devices, the rotational speed of the fan can be controlled, enabling adjustment of the airflow rate through the chamber.

There are two options for supplying the new RH chamber with sample air from dew/frost point generators. The first option is to use the adapter fittings, developed within this project, to connect the desired tubing to the inlet and outlet of the RH chamber assembly. The second option is to use a small cylindrical sub-chamber(s) in combination with the new RH chamber. In the latter case, the sample air is led directly to the relative humidity sensor, minimising the area of surfaces that are in direct contact with it. This leads to a reduction of uncertainty related to the adsorption of water vapor on those surfaces. Since the gap between the small sub-chamber and relative humidity sensor is small, the air streams above it with higher velocity than would be the case with a more considerable gap (for example, when a small sub-chamber is not used). Since the heat exchange rate between the sample air and RH sensor increases with the increase of air velocity, the uncertainty related to self-heating of this sensor is reduced as it is cooled more efficiently. The small working volume of the sub-chamber also leads to quicker stabilisation after the change of sample air temperature or dew-point temperature to a new value. Considering the identified needs for relative humidity measurements in participants' countries, the new RH chamber was designed for relative humidity range between 2 %rh and 95 %rh at temperatures between -60 °C and 100 °C. Besides humidity measurements, the new chamber is appropriate for use in temperature laboratories for the calibration of air thermometers.

The new RH chamber was manufactured in Italy, where a preliminary performance evaluation was also carried out. In this research, the process of designing, producing and characterising the calibration sub-chamber was studied. Experimental work was also carried out on a copy of the new RH chamber to increase the practical understanding and to learn and apply good practices and methodologies to the future characterisations. The initial characterisations were performed with the new RH chamber accommodated inside two climatic chambers, in the temperature range from 1 °C to 70 °C. The results indicated a significant reduction of temperature gradients and related measurement uncertainties in 11 out of 14 measurements (improvements are between 400 % and 2400 %; 1000 % on average). At two measurements, improvements were moderate (approx. 50 %). At one measurement, the standard uncertainty was increased from 4.4 mK to 8 mK. Besides the determination of temperature gradients, characterisation at INRIM covered determination of temperature stability, pressure drop and purging time. The above experimental work was carried out under the scope of a Researcher Mobility Grant by a researcher from JV. The experiences in setting up and using the new RH chamber, gained through preliminary investigations, were shared with project partners within the scope of a workshop held at INRIM. A characterisation protocol was prepared, and related measurements performed at INRIM, IMBiH, DMDM, NSAI, ME-BoM, MER, UL and FSB. The considered parameters were temperature stability, inhomogeneity and dew/frost point stability inside the working volume of existing climatic chambers and the new RH chamber. The chamber was characterised through 28 measurements, in the range from -60 °C to 100 °C. Improvements were achieved at 26 measurements, ranging from 3 % up to 1003 %. The corresponding standard uncertainties, for calibration of relative humidity instruments in the range from 2 %rh to 95 %rh, are between 0.003 %rh and 1.38 %rh. In two laboratories, the new RH chamber enabled the extension of the temperature range for calibration of relative humidity instruments.

The outcomes, including guidelines on the standardised design, have been promoted and disseminated to the relevant industrial stakeholders, thereby improving confidence in humidity calibrations throughout Europe.

Objective 3

To organise and undertake an intercomparison of relative humidity measurements using the small chamber to underpin and validate the procedures developed and measurement capabilities of the participants.

An interlaboratory comparison in the field of relative humidity measurements was organised for determination of the degree of equivalence among the partners as well as for the verification of the overall improvements achieved in participating laboratories through participation in this project. The intercomparison covered the relative humidity (RH) range 10 %rh to 95 %rh at gas temperatures from -10 °C to 50 °C. Although the intercomparison was initially planned only among the project partners, in order to increase the project impact it was decided that it would be extended to include EIM - Greece and JV - Norway. Following production of the new RH chamber and the dissemination workshop at INRIM, two sets of transfer standards were obtained from the project stakeholder Rotronic UK and collaborator Alius grupa d.o.o. The intercomparison protocol was then prepared and submitted to the EURAMET TC-T chair after which it was registered at the EURAMET under registration no. 1442. The intercomparison protocol follows all the relevant guidelines established by the BIPM and EURAMET communities. Also, the technical procedures detailed in the protocol are based on current best practice in the use of relative humidity meters (hygrometers) also considering the experience gained from regional comparisons over the years. Therefore, it can be reused as the template for the future RH intercomparisons organised at national and international levels. All the project partners plus EIM and JV finished the intercomparison measurements using the new RH chamber. Analysis of the intercomparison results showed a good agreement among the project participants, confirming at the same time the improved uncertainties achieved by using a new RH chamber. It is worth mentioning that seven of the 12 participants in this intercomparison do not have CMC values for calibration of relative humidity sensors published in the BIPM key comparison database (FSB, CMI, ME-BoM, MER JV, DMDM and TUBITAK) and that this intercomparison covers a temperature range which is wider than the ranges published in the KCDB for IMBiH (20 °C to 24 °C), UL (-10 °C to 20 °C), NSAI (5 °C to 60 °C) and EIM (10 °C to 70 °C). Therefore, the results from this intercomparison would be valuable to almost all the participants as supporting evidence during the submission of new or improved CMC claims to the BIPM for publication in the KCDB. Also, for two of the laboratories, this was their first participation in an intercomparison registered at EURAMET in the field of relative humidity measurements.

Objective 4

To improve research capacity in the field of dew point measurements by systematic review and improvement of dew point generators. The target uncertainties are between 0.05 °C and 0.1 °C for a temperature range of -70 °C to 90 °C. To implement the improved dewpoint capability into the national/regional traceability infrastructure.

A survey regarding dew point measurements was performed to find out needs and requirements of stakeholders and capability of the partners. The results have enabled optimal solutions for dew point setups to be suggested for each individual partner. Individual requirements and needs were discussed with each partner separately to find out the optimal solution for each of them and to meet the needs of their national stakeholders. A report on the technical documentation indicating a methodological approach to design solutions for improved dew point generators for these partners was prepared.

There are three types of laboratories in the project. The first type is the well established primary laboratory system, where only a few adjustments are proposed. The second type is the laboratories where a primary generator already exists and there is a need for validation or improvement. The third type is laboratories without a primary system and with no need to make it.

The current state of dew point measurement was determined within each partner institute and technical documentation on how to improve their respective measurement uncertainties were prepared. This was achieved by modifying factors of influence, such as flow rate, pressure, temperature range, bath performance and tubing type. Each partner then reported the improvements achieved in temperature range and uncertainty. Overall, improvements in dew point capabilities at partner laboratories have permitted the realisation of dew point temperatures ranging from -70 °C to 90 °C. The improved capabilities also led to the achievement of target uncertainties as low as ±0.05 °C to 0.1 °C, a significant improvement on capabilities prior to engaging in the project.

Objective 5

To develop individual strategies for the long-term development of research capabilities in humidity traceability including a strategy for offering calibration services from the facilities established to customers in their own country and neighbouring countries, through questionnaires and workshops organised in the local language, which will involve the broadest spectrum of stakeholders. The individual strategies will be discussed within the consortium and will lead to an overall strategy document to be presented to the EURAMET TC-T, to ensure that a coordinated and optimised approach to the development of traceability in this field is developed for Europe as a whole.

An overview of the experienced partners' individual strategy documents in metrology or in the humidity subfield was presented at the beginning of the project based on the CIPM Consultative Committee on Thermometry (CCT) strategy and the regional strategy of EURAMET. This led to the development of a draft template for individual long-term strategy documents for the participating emerging countries.

Individual strategy documents for humidity research and development of the associated capabilities in Serbia, Bosnia and Herzegovina, Montenegro, Ireland, North Macedonia, and Croatia were subsequently prepared and adopted by the respective NMI/DIs in the project consortium.

Each individual strategy document proposes a long term strategy, over the next five to 15 years by national requirement, taking into account future humidity measurement capability requirements and the need for developments especially linked to environmental, health and energy topics.

The individual strategy documents were summarised in a single strategy document, which reports an overview of future requirements and developments in the humidity subfield for NMI/DIs from emerging countries. The long-term strategy document was prepared within the scope of regional coordination with the aim of promoting small specialisations, taking care to avoid duplication of humidity resources, and was promoted at EURAMET technical meetings, national workshops with or without stakeholders, regional and local conferences, etc. The document will be updated with the latest technological advances and will adapt to changing stakeholders needs by undergoing a review at least every three years to reflect any changes in regional or national needs.

5 Impact

A project website was created and updated regularly with news of the project, along with an associated LinkedIn profile.

A training course in humidity was held for consortium members and interested parties in January 2017. This course covered all aspects of humidity measurement and allowed for extensive discussion of the regional measurement requirements and capabilities. The training had a significant impact on the knowledge of each consortium member.

The second training course was held for consortium members in October 2017. The focus was on the installation, set-up, and fine tuning of the chamber within a chamber system for humidity measurements. During the meeting, the inner chamber characterisation protocol was presented and discussed by the partners. The final version of this document was prepared following separate characterisation of the chamber in each partner country when the inner chamber was circulated in 2018.

A stakeholder training working group was set up by the consortium members with the aim of preparing training material to assist in training of stakeholders within each member region. The material includes a course overview, presentation slides and exercises to be carried out by attendees to improve their understanding of humidity measurement. All material is available for delivery by partners in their respective regions.

Stakeholder workshops were held in the partner countries, using the materials prepared by the working group. Feedback was unanimously positive, and will guide future research in the field of humidity among the partners.

Impact on industrial and other user communities

The small chamber within a chamber approach should reduce the time needed for a calibration and so will increase the time that each instrument is available to the owner for measurements at their facility, reducing operation and maintenance costs.

Through the development of training courses in humidity measurement, the outcomes of the project, as well as general humidity measurement training have been delivered effectively to industrial stakeholders, thereby improving understanding and skills among industry within the European Union.

Through the development of best practice guides in the fields of Relative Humidity and Dew-point measurement, a standardised approach has been made available to end users throughout Europe, as well as an improved understanding of the most appropriate measurement techniques and sources of error associated with each field.

In the area of relative humidity and dew point measurement, knowledge transfer from experienced NMI/DIs to those less experienced in how to use new types of humidity instruments and facilities has been very beneficial. It has helped to raise the knowledge, measurement and research capabilities and is promoting consistency within humidity metrology.

Through highlighting the importance of humidity to processes, and to human comfort levels, the results of this project will lead to a better understanding of humidity among stakeholders and therefore to an improvement of environments with climate control, as well as humidity or moisture dependant industrial processes. A better understanding of humidity measurement and control will also allow the development of optimal storage conditions for produce, leading to a reduction in waste and spoilage throughout Europe.

Impact on the metrology and scientific communities

The validated calibration techniques and associated uncertainty formulation developed in the project at emerging NMI/DIs will be used directly by calibration laboratories, which will assure traceability of measurements performed using different humidity sensors. Measurement results will be reported with the associated measurement uncertainty, which will enable their transparent comparison and comparison of the performance of various humidity sensors. Dissemination of traceability amongst NMI/DIs will provide access to improved capabilities for national and accredited laboratories and support consistency in measurement capabilities. Harmonised and traceable calibration, usually based on accreditation, is a basic requirement for mutual recognition of calibration results, offering a cost saving to European exporters. The recognised traceability of calibration results will also provide an important contribution to consumer protection.

The RMG researchers' work will bring increased technical skills in the humidity fields and also increasing capacity in research in their countries, it is a good opportunity for further growth and development of NMIs.

The improved capabilities developed at the participating laboratories will result in better uncertainties in the calibration of humidity instrumentation and hence will provide customers with a clearer picture of how their equipment is performing year on year thereby allowing better control of their processes.

Impact on relevant standards

By identifying relevant standards which involve humidity measurements, it will be possible to determine the range and accuracy requirements which would permit industry to comply with these standards. Where the humidity measurement expectations are considered unachievable or unrealistic by the consortium, this information will be communicated to the relevant standards committee with a view to influencing future drafts of the standards.

IEC TC 82, CEN, TC 346, IEC TC 47 and IEC TC 50 were identified as the most relevant Technical committees to this project. These committees were contacted and informed of the aims of the project. Once the results and conclusions were compiled, these were sent to the convenors for dissemination among the committee members. This has led to expressions of interest in future research from the committees, as well as an invitation for the partners to join the technical committees and actively participate in the development and improvement of standards in future. Where deemed relevant, the results will be considered when compiling future drafts of the standards.

Longer-term economic, social and environmental impacts

Establishing traceable measurements in humidity at the level needed by each participating country will enable important inputs for areas of research, innovation and patenting in this field in future EMPIR projects. An important aspect of this project is the collaboration of less experienced NMI/DIs with experienced NMI/DIs. The upgraded skills and expertise in emerging countries' NMI/DIs will be applicable to industrial purposes, and the development of practical tools in the form of guidelines and procedures for enhancing the transfer of new capabilities to end-users is also expected.

Through highlighting the importance of humidity to processes, and to human comfort levels, this project will lead to a better understanding of humidity among stakeholders and therefore to an improvement of environments with climate control, as well as humidity or moisture dependant industrial processes. A better understanding of humidity measurement and control will also allow the development of optimal storage conditions for produce, leading to a reduction in waste and spoilage throughout Europe. Following the long term strategy by each partnering country gives better economic, social and environmental impact, also.

6 List of publications

1. *Expansion of European research capabilities in humidity measurement*, N. Hodžić, S. Čohodarević, N. Jandrić, R. Strnad, D. Sestan, D. Zvizdic, V. Fernicola, D. Smorgon, L. Iacomini, S. Simic, D. Mac Lochlainn, N. Karaböce, S. Oğuz Aytekin, J. Bojkovski8., D. Hudoklin, O. Petrušova and T. Vukicevic, 18th International Congress of Metrology (2017) 06006, http://dx.doi.org/10.1051/metrology/201706006
2. *Improving emerging European NMIs' capabilities in humidity measurement*, N. Hodžić, S. Čohodarević, N. Jandrić, R. Strnad, D. Zvizdić, D. Šestan, V. Fernicola, D. Smorgon, L. Iacomini, S. Simić, D. Mac Lochlainn, N. Karaboce, S. Oguz Aytekin, J. Bojkovski, D. Hudoklin, O. Petrušova and T. Vukičević, Journal of Physics: Conf. Series 1065 (2018) 122019, http://dx.doi.org/10.1088/1742-6596/1065/12/122019
3. *Development and preliminary investigation of a modular chamber for calibration of relative humidity instruments*, D. Šestan, D Smorgon, P. Rothmund, L. Iacomini, K. Šariri, V. Fernicola, D. Zvizdić and N. Hodžić, Journal of Physics: Conf. Series 1065 (2018) 122017, http://dx.doi.org/10.1088/1742-6596/1065/12/122017

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