FINAL ACTIVITY REPORT (WHOLE PROJECT)

Collective Research Project

Contract: COLL-CT-2004-500736

Acronym: PREWIND

Title: Development of a Methodology for Preventive Maintenance of Wind turbines through the use of Thermography

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Table of content

Publishable executive summary

Wind-Energy plays an important role not only as an economic factor and for the Environment and climate protection, but also as a secure power supply, fulfilling already the electricity needs of more than 35 million people worldwide. The sector has been growing at an average rate of 40% annually over the past 5 years, having at the moment an annual turnover of more than 5 billion Euros world wide and employing around 70,000 people.

Nearly three-quarters of the world-wide wind power capacity is installed in Europe and more than 80% of the wind turbines sold worldwide are made by European companies. Of that total, more than 23000 MW are installed, enough energy to serve 16 million average European homes.

Europe continues to lead the way of acceptance of this rapidly advancing power generation technology. Most of the future growth of the wind power sector in Europe is expected to be in offshore applications.

Wind turbine operators are aware that wind turbines must be maintained in good conditions, not only to prevent accidents or damages, but also to lower their operational costs and so to high-up their performance. This is also vital for the companies manufacturing the units and for the companies providing the maintenance services, as well as for insurance companies.

It stands out that there is a *market niche* for innovative quality assurance applications for wind turbines, both onshore and offshore. Therefore, it is the intention of the PREWIND Consortium, through a collective research project, to define of a common quality methodology for wind turbines.

The main objective of PREWIND is to develop a certified methodology for assuring the quality of wind turbines through the application of thermography. The methodology will be applicable to all wind turbines (onshore/offshore) by wind turbine operators, maintenance companies, manufacturing companies, insurance companies, etc.

The PREWIND methodology will reduce the amount of large-failures that occur during the normal functioning of a wind turbine (e.g. damages to the rotor-blades due to vibration or oscillation, etc.), since they will be detected at an early stage, so that corrective actions can take place before the damages become critical. This means that by applying this methodology, the life time of the wind turbines can be extended and maintenance costs can be reduced. Furthermore, this methodology is not limited only to maintenance applications, thus it can be also applied for quality assurance during the manufacturing of the components or after the transport or assembling of the wind turbine during its installation.

But what is thermography?

In a general sense, thermography is a non-destructive method that involves measurements and graphing of isothermal contours on the surface of an object, displaying the effects of temperature differences in its material. Some elements of a wind turbine generate themselves temperature differences during their functioning (E-generator, brake discs, etc.), and can therefore be easily analysed through thermography (passive thermography).

For the other parts (GRP[1] rotor blade, tower, etc.), a suitable heat source has been developed to induce energy into them and thereby characterize defects on a more qualitative basis (active thermography). The so-called Lock-in[2] thermography has been tested in laboratories and has showed great success, detecting for example, delamination in GRP, or finding the beginning of corrosion before it appears on the surface. Different techniques have been tested during the project to assure optimised results.

[1] GRP: Glass reinforced Plastic is the correct term used to describe the form of construction often addressed as glass fibre or fibreglass, although the latter is the trade-mark of a company producing glass fibre materials. The plastic is normally a liquid polyester resin, which is mixed with a catalyst (in this case hardener) and used to saturate layers of cloth made from strands of glass fibres. When this has cured it forms a very strong laminate of resin and glass.

[2] Lock-in thermography refers to the need for synchronization of both input (modulated heating) and recorded signal.

It is a fact that although GRP materials consist of two distinctly different phases, a properly laminated composite material will have relatively uniform thermal characteristics. Once a delamination or other anomaly has occurred, the thermal pattern within the composite will be altered. Because different materials possess different values of thermal conductivity, regions such as disbands or air inclusions tend to build up / or to retain heat, thus indicating the location and size of the damage. This way, it is possible to detect through the thermographic camera a small “inhomogeneous” section in a rotor blade at an early stage, before it becomes bigger.

Electrical connections can be also controlled, thus in abnormal situations, the temperature tends to rise. Also a lack of lubricant in the shaft would lead to an increase due to friction, the normal operation temperature. All being characteristics detectable by a thermographic camera not bigger than a normal video camera, but offering vast possibilities when operating with the adequate method.

The IAGs in PREWIND play a key role as they are an important source of input/feedback throughout the whole development of the methodology. They have access to a large number of SMEs and other companies, which are their members.

The SMEs participating in the project are forming the so-called core group and are representative for the overall value-added chain of the wind energy technology. A well-balanced group of SMEs has been achieved, combining expertise in the different fields involved in this development (from manufacturers of components, to companies involved in maintenance activities, till NDT service providers companies). They have a very important function supporting the RTDs with their practical experience, and carrying out some of the technical work in the project.

The RTDs are responsible for carrying out most of the technical work during the project. The RTDs participating in PREWIND have the complementary competences and expertise necessary for carrying out the required tasks in the project.

A short profile of the different organisations involved in this project can be found in the project webpage under www.prewind.net.

In order to secure a comprehensive management of the project, taking into account its considerable dimension (three years duration and 16 partners), it has been considered advisable to divide the management tasks in three parts: administrative management, scientific management, and knowledge management carried out respectively by TTZ, Alphatherm, and Automation Technology and FGW. The overall project management is responsibility of the Project coordinator, which is TTZ Bremerhaven (www.ttz-bremerhaven.de - contact person: Mr. Cristian Ferber email: cferber@ttz-bremerhaven.de).

Section 1 – Project objectives and major achievements

1.1. General project objectives

The main objective of PREWIND is to develop a methodology for assuring the quality of wind turbines through the application of thermography. The methodology will be applicable to all wind turbines (onshore/offshore) by wind turbine operators, maintenance companies, manufacturing companies, insurance companies, etc.

The PREWIND methodology will reduce the amount of large-failures that occur during the normal functioning of a wind turbine (e.g. damages to the rotor-blades due to vibration or oscillation, etc.), since they will be detected at an early stage, so that corrective actions can take place before the damages become critical. This means that by applying this methodology, the life time of the wind turbines can be extended and maintenance costs can be reduced.

Furthermore, this methodology is not limited only to maintenance applications, thus it can be also applied for quality assurance during the manufacturing of the components or after the transport or assembling of the wind turbine before it is put into service.

This project represents a considerable progress beyond the current state-of-the-art in the preventive maintenance of wind turbines. It will provide a new standardised and certifiable working methodology for the preventive inspection of the units. Compared to other industries, (e.g. the automotive industry), where certified maintenance and quality processes are established, there is still a high potential for certified maintenance and quality methodologies in the wind energy sector.

Today, manufacturers of rotor blades take care of their production process following quality standards, etc., however there is no company capable of testing the final product adequately (at least in an automated way, the technology is not so developed yet). Nowadays, for the most companies manufacturing rotor blades, the final check of a rotor blade consists of a visual inspection by an expert, who with a “screw-driver” knocks on the GRP material and out of the sound he perceives, he determines if the part is OK or not. This requires a highly trained ear, and lots of experience. It must be remarked then, that this commonly used method relays 100% on a humans-factor and therefore is susceptible to errors.

Only a very small minority of manufacturers of blades have already discovered the advantages of thermography and apply (passive) thermography on recently manufactured blades. The heat generated by the chemical reaction of the used resins is monitored, and so the conclusions about the adhesion of the parts are deduced. It must be commented also, that once the heat generated by the chemical reaction is gone, no further tests can be performed using this method.

The method proposed in this project for the Non destructive technologies (NDT) testing of the components does not have that time “restriction”. Through the application of active thermography, the tests can be performed at any stage of the life on the rotor blades: after their manufacturing, prior to their installation or even after they have been working for some years. This is the big advantage of PREWIND towards the state of the art.

Wind energy associations are aware of the importance of improvement in the maintenance of wind turbines for the whole wind energy sector. PREWIND will represent a huge improvement paving the way for obtaining a certified methodology assuring a high degree of reliability for wind energy. High quality operation obtained through the use of a common certified methodology will lead insurance companies to save money through the lower occurrence of failures. So wind turbine operators will save money in lower insurance fees, maximizing their profit. Further maintenance companies will save money through the higher rate of success in maintenance actions and the reduction of the time required for them, optimising their work.

Conclusion:

After the finalization of the project PREWIND the consortium can conclude the following:

- The consortium determined the main areas of interest to emphasize the efforts of study for the application of thermography for the improvement of the preventive maintenance of wind turbines: the rotor blades (active thermography), and the electrical components (passive thermography)
- The consortium managed to select the most suitable technology/components for the PREWIND method: type of camera, type of heat source, etc.
- The consortium managed to develop a method for the preventive maintenance of wind turbines using thermography.
    - Active Thermography: the different tests carried out during the development of the project, proved that it is possible to inspect rotor blades while mounted on the wind turbine. The consortium was able to detect failures in the structure of the blades such as delaminations, areas with insufficient adhesion (glue) of the inner reinforcements of the blade, etc. up to a depth of about 12mm (depending on measuring parameters).
    - Passive Thermography: the consortium developed a procedure for the inspection (& documentation) of the electrical components of wind turbines, to enable the detection of failures at an early stage. For this type of inspection any regular IR-camera can be used.
- The consortium generated all the documents, procedures, etc. to have the PREWIND method certified.
- The information generated during the project was disseminated by the IAGs to their members (at workshops, seminars, …); and by the whole consortium during their presence at related fairs, etc.

Although the PREWIND field tests proved the method to be successful, at least the Active-Thermographic-inspection still would need to be optimized to improve the practicability of the inspection on a commercial basis. All the partners agreed that it is very valuable to detect the status of a rotor blade, however with the system at its current level of development would be too expensive for the inspection of a smaller unit. The consortium sees two very interesting opportunities for the PREWIND-application:

1. for the inspection of “bigger” wind turbines (5MW, particularly off-shore units, where effective preventive maintenance is crucial)
2. the application of a “reduced” and more “simplified” PREWIND-system, which is only serves to detects failures in rotor blades roughly (failures near to the surface are particularly critical). In this case it is not so interesting to know the exact size and depth of a failure; the crucial point is to detect if there is a failure or not. In the case of a failure the rotor blade would be repaired anyway. This simplified “PREWIND” would be cheaper to be used by maintenance companies, and therefore more commercially interesting.

1.2. Comment on the most important problems during the whole duration of the project and corrective actions undertaken.

Although there where some minor delays in some tasks during the development of the project, the consortium managed to catch up. These delays were mostly generated by the inaccurate estimation of resources for some tasks during the preparation of the proposal (e.g. the testing phase); therefore the consortium had to dedicate a bigger effort than originally foreseen, to be able to conclude the tasks successfully.

The most considerable difficulty however, was the desire of two partners to abandon the project: the IAG ISES and the SME partner TEGOPI. Both partners expressed to the coordinator their intentions to withdraw from the project's consortium.

The corrective measure for this issue was to find two replacements for these partners. At this moment, all the documents are being prepared to do an amendment to the project's contract, to make the partner exchange official.

So, the IAG ISES was replaced by APER, and TEGOPI was replaced by the SME ILIAKO.

Section 2 – Work-package progress

We will start this section with a summary of the work carried out during the 1st reporting period (to report the outcome of the Work-package A and of the Tasks B1 and B2).

Work-package A – Definition of Technological Requirements (recapitulation of the 1st reporting period)

The following table shows the amount of personnel resources planned for this work-package per participant and the amount used (more detailed information can be found in the Annex 1 of the Periodic Activity Report - 1st Yearly report).

Work Package A: Person-Month Table per Partner																	
		IAGs						SMEs						RTDs			
	TOTALS	FGW	APPA	APREN	ISES	IWEA	GEAL	Alphatherm	TEGOPI	Reetec	Krypton	EED	Jonica	TTZ	AT	AmbiQual	CRIC
Used	34,39	2,50	2,73	2,25	1,40	1,75	2,52	2,70	0,00	2,50	1,50	0,90	1,51	4,59	3,04	3,00	1,50
Planned	38,50	3,75	2,75	2,25	2,25	2,75	2,75	2,50	1,50	1,50	1,50	1,50	1,50	4,50	2,00	4,00	1,50

2.1.1. Work-package objectives and starting point of work at the beginning of the 1st reporting period

The objective of this work package is to specify the requirements of the PREWIND Methodology in accordance with the end user's needs (SME partners and members of the associations). It is necessary to consider in this task usual failures/problems of wind turbines for the development of the working methodology in work package B, as well as quality control methods, international and national requirements for the manufacturing of wind turbines and quality standards.

2.1.2. Progress towards objectives (recapitulation of the 1st reporting period)

Task A1 - Specification of technical problems for wind turbines (recapitulation of the 1st reporting period)

The main aim of this task was to gather as much information as possible on the situation of the wind energy sector: amount of wind turbines in the countries represented, data on maintenance routines, to identify the main problems/failures in wind turbines during: manufacturing procedures, maintenance procedures, software, working times and currently most common practices, etc.. For this purpose, a target oriented questionnaire was be developed by TTZ with the support of the other partners (See D01 of this report), and was distributed to the associations and SME partners involved in activities related to the wind energy sector.

This task has a significant importance, since it will provide the basis for the later definition of the technical specifications for the PREWIND (Deliverable 04), where the most critical failures of wind turbines, as well as the application of thermography to improve their prevention, will be analysed.

Unfortunately, non of the participating IAGs was able to obtain a response from their members to the questionnaire, because they where told in all cases, that the information required is strictly confidential (decision that is respected by the PREWIND consortium).

However, the IAGs and partners to whom the questionnaire was distributed, in order to not interrupt the normal development of the tasks in the project, provided diverse information, as for example, data about the wind energy sector in their country of origin, etc.

- FGW: provided literature and statistical data on the failures of wind turbines (, obtained from different meetings with insurance companies, and related workshops in which they have been represented.
- APPA: Provided a copy of a Press Release from APPA related to the wind energy sector in Spain. The information provided shows the evolution of the branch over the years, as well as the distribution of wind turbines (installed capacity) per provinces.
- APREN: responded to the questionnaire trying to summarise the information of the Portuguese wind energy sector.
- ISES: provided informal information, giving a general characterization of the wind energy sector in Italy.
- IWEA: provided information on the wind energy sector in Ireland, and statistics.
- GEAL: provided information about the Irish wind energy market, and feedback on the local legislations.
- EED: provided information on the wind energy sector in France.
- Jonica: provided data about the capacity of wind turbines installed in Italy, and about the turbines that the company manufactures.

A meeting took place, at the facilities of Reetec, where personnel of Reetec, Krypton, Alphatherm, FGW, Automation Technology, Alphatherm and the TTZ where present.

Reetec and Krypton commented the questions of the questionnaire:

- Possible failures during the manufacturing procedure of wind turbines: failures in the electrical connections, in the hydraulic system, problems with malfunction of the sensors used for the remote monitoring and damages to the rotor blades.
- Possible failures caused during maintenance actions: damages to cables, modem not properly reconnected (in units from GE Wind), among others.
- Possible failures in the control software: PLC's or SCADA not working properly for the operation monitoring.
- Although they commented that it was very difficult to say the average time required for the most common maintenance actions (it varies too much, depending on where the wind turbine is located and its accessibility, on the type of wind turbine, the age of the unit, etc..), however, they would estimate about 1 or 2 days per maintenance team (consisting of two technicians → 2 to 4 Man-days).
- It was commented that all wind turbines have to be inspected by a certified team once a year (requisite of the insurance companies). These teams can be maintenance companies, or personnel belonging to the manufacturer of the wind turbine (this varies from brand to brand).
- About the type of wind turbines, they commented that there where basically two types:
    - The ENERCON wind turbines
    - The rest of wind turbines

  This is related to the construction of the wind turbine itself, where ENERCON is the only one differing from the rest, because their turbines have a gearless system with a ring generator.

- It was commented that the insurance companies with the most market share of the branch are: Allianz, Gothaer, AXA and March (Off-shore).
- The draft of the general inventory of parts (Deliverable 7) was revised.
- Krypton provided an overview of the wind energy sector in Germany: market-share of the different manufacturers of wind turbines, as well as the data of wind turbines per federal state (amount of wind turbines, installed capacity and average kW per wind turbine).
- Reetec provided an anonymous example of an inspection to the rotor blades of a wind turbine, as well as some pictures of the equipment used for these tasks. This information is very helpful for the development of the procedure for the inspection of wind rotor blades using the PREWIND system, as well as how these inspections have to be documented.

The information provided by the project partners, as well as its assessment, can be found summarized in the annexes D1 & D2 of this report.

In addition, TTZ contacted Gothaer Versicherungen, and FGW assisted to conferences with personnel of Allianz, so that it was assured that sufficient information from the side of the insurance companies was also available.

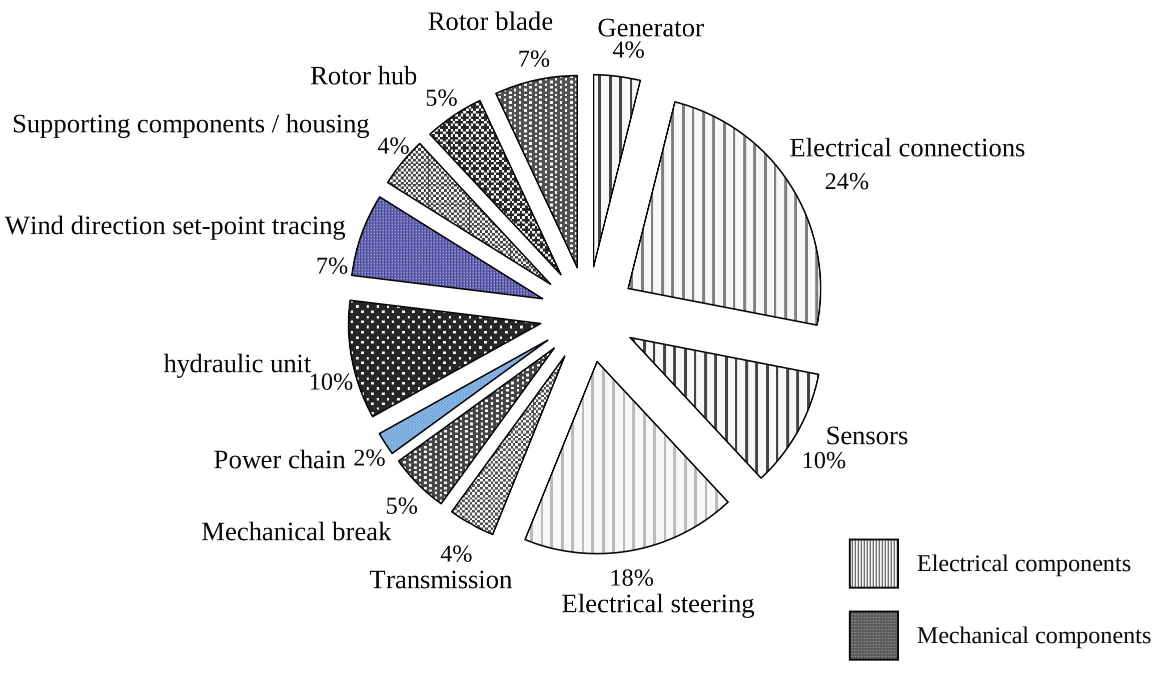
Another aim of the task A1, was to the summarize information on the breakdown of wind turbines and analyze the most critical failures in a technical specifications document.

The work carried out here is based on the information gathered from Assessment of filled-in Questionnaires (Deliverable 02), from interviews to project partners, from interview to insurance companies (Allianz, Gothaer) and from an exhaustive internet and literature research carried out by the consortium.

Following, an analysis of the failures that lead to operation disruption of wind turbines:

Even with strict measures for controlling the operation of wind turbines, failures still occur. The following analysis takes only into consideration only unpredicted failures, of which a little bit more than half of them, are caused by malfunctions in the electrical connections or electrical components. The main components, such as the rotor blades, the transmission or the generator, do not stand out due to their failure-frequency (see Fig.1).

Graphic 1: Share of each main component of a wind turbine on the amount of failures

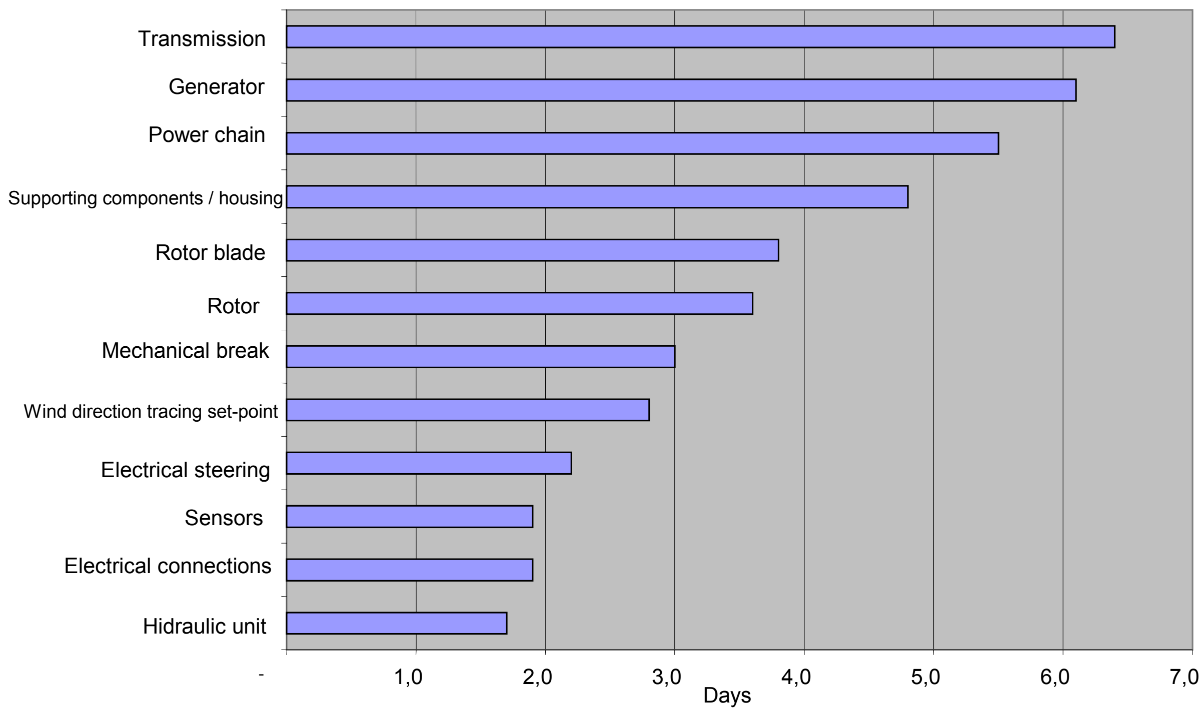


The amount of failures is however, is not an indication of the seriousness of a failure. To evaluate this, it has to be considered, the frequency of the failure, the operation disruption it has caused, and the maintenance costs to have it repaired. Due to the fact, that malfunctions are often take place in more than one element at a time, it is very difficult to isolate the costs caused by the failures of each component. Many times these costs are also diluted in routine maintenance activities. Therefore for this analysis we will take only into consideration the frequency of the failures and the operation disruptions it has generated.

The operation disruptions also depend on the required repair works, on the availability of the spare parts as well as on the availability of the Service-Team. Particularly maintenance activities on elements such as the generator, rotor blades, transmission, etc. can take even weeks to be concluded.

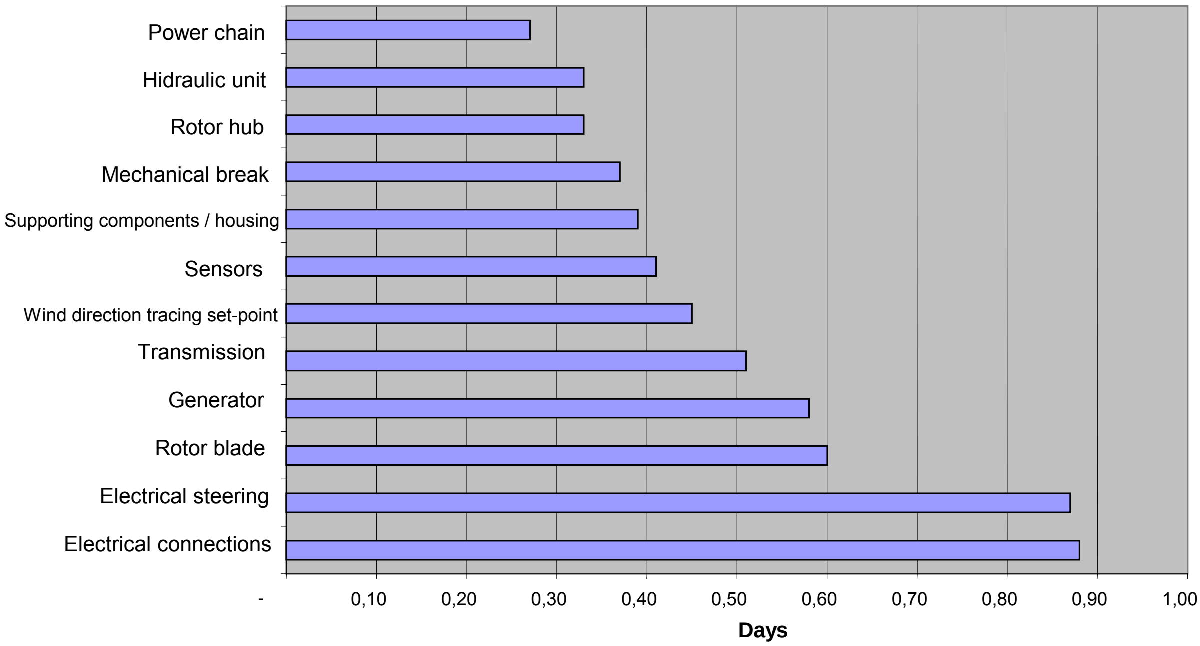
The following table shows the average operation disruption in days per failure of each main component:

Graphic 2.: Average operation disruptions per failure



As it was commented before, electrical components stand out for their frequency of failures. However, those failures can be repaired relatively fast, within a period of 1 or two days. From the relation between frequency of failures and operation disruptions they caused, we can analyse the reliability of a wind turbine inn a more precise way.

Graphic 3: Average operation disruptions of a wind turbine per year, in relation to the frequency of failures and the stand time they generate



From the Graphic 3 we can see that failures in electrical connections or in the electrical steering only generate about three times more disruptions times than failures in the power chain, even though they have a frequency of occurring about ten times bigger. Nevertheless, failures in the electronic connections or in the electrical steering generate the most stand-by time of wind turbines.

Following a brief description some types of damages in wind turbines:

Mechanical damage includes both damage to the actual machinery and other types of damage suddenly occurring to the wind turbine, e.g. mechanical damage to the rotor blades other than damage caused by lightning or storm. The most frequently occurring type of mechanical damage is damage to the gears. Damage may happen to bearings due to breakdown or wear, backlash and tooth breakage. These types of damage usually occur due to defects in material, fatigue, the use of wrong oil or wrong oil temperature, vibrations and overloading.

Minor types of gear damage can often be repaired on the spot, whereas more serious types of damage, which involve the lifting of major spare parts up to the nacelle, often find a more worthwhile solution in a replacement of the gear, as this will reduce the interruption time and requires only one call for a crane. Moreover, it will often be possible to sell the damaged gear to the manufacturer. The repair time at the gear manufacturing plant and the time of delivery of a new spare part will usually determine the repair method to be chosen.

Mechanical damage may also happen to the rotor blades. So-called edgewise vibrations which arise in case of a combination of a specific temperature and a certain wind speed may cause the rotor blades, and even the whole wind turbine, to start shaking up to the point where, in the worst case, the result is a total loss of the unit. The problem of vibrations should have been solved for wind turbines produced in recent years through improvements to the construction of the rotor blades.

Damage by lightning is the second most frequently occurring type of damage. However, the extent of damage differs widely from one case to the other. Damage by lightning can be anything from be a minor damage to the electric control panels, up to a total damage to the rotor blades, gearbox, generator, and control system. Failure to install protection against lightning will cause the electric charge to travel through rotor blades, gearbox and generator and to the control panel where it may cause considerable damages.

Damage by fire in wind turbines is usually caused by overheated bearings, or by a strike of lightning or by sparks thrown out when the turbine is slowing down. The possibilities of fighting a fire in a wind turbine are often severely hampered due to the height of the tower, inadequate or non-existing access roads, or sittings in the countryside (or offshore) far away from the nearest fire-fighting service. Consequently, even the smallest spark can easily develop into a large fire. Fire in wind turbines usually lead to a total loss of the nacelle and the rotor.

Conclusions:

1. The safe and failure-free operation of wind turbines can only be achieved through an optimized preventive maintenance programme.
2. An optimized preventive maintenance programme, is only possible through a good operation monitoring system.
3. Wind turbines can reach their estimated lifespan (and be for all involved parties an economical success), when Fact 1 and 2 are fulfilled.
4. The most critical parts to be taken care of for the better operation of a wind turbine, according to the information gathered in this document, are the electrical connections and electrical systems, as well as the rotor blades in third position.

The aspects contained in this analysis can vary from country to country. It serves however its purpose by providing a good overview on the main aspects that lead to failures on wind turbines, and therefore will serve as a basis for the following tasks to be carried out during the PREWIND project.

Task A2: Identification of the relevant laws and certification standards/procedures (recapitulation of the 1st reporting period)

AmbiQual, with the support of the IAGs and SME partners carried out a comprehensive research of relevant National and European laws, quality standards and certifications procedures. This will help to determine the necessary procedures to achieve the certification of the final PREWIND Methodology. Different authorities as well as certification bodies (e.g. TÜV, SGS etc.) were contacted and the results summarized in a certification requirements document containing the necessary steps and information for certifying the PREWIND Methodology.

AmbiQual decided to divide the task A2 in two sub-tasks:

Sub-task 1: Identification of the applicable Wind Energy international and national laws, standards, specification and requirements, and

Sub-task 2: Identification of the necessary steps and information to certify the final PREWIND Methodology.

Several actions were defined and carried out to achieve the objective proposed by the subtasks 1 and 2. For example:

- Questionnaires were elaborated and sent to all the members of the consortium:
- Exhaustive Internet research related with the following topics: Wind Energy European and national laws, Standards, specifications and requirements.

- Research about existing specifications and requirements for certification of Wind Energy systems.
- Interviews were performed to certification entities;

All the information collected by this task is summarised in several tables that explain the relevant International, European and national laws. As well as standards, specifications and certification requirements documents that provides guidelines for certifying the PREWIND Methodology.

By following the project working-plan it is possible to find the task B4 “Development of working methodology”. The task B4 will gather the results that have been researched and developed in the task A2. This way we can improve the project results and assure correct development of the working methodology for future certification.

As result of this task we have identification of relevant EU Directives, National laws, standards, specification and requirements, as well as the definition of the necessary procedures to achieve a certification of the final PREWIND methodology.

As stated before AmbiQual, divide the task A2 in two sub-tasks. The first sub-task was the; Identification of the applicable Wind Energy international and national laws, standards, specification and requirements. During this task several actions were carried out. For example:

- Specific questionnaires sent to all the members of the consortium:

Specific questionnaires were delivered to project partners to achieve certification of the final PREWIND Methodology. The main focus of this action is to identify relevant laws and certification standards/specification procedures related to wind turbines; production, transport, installation, operation, maintenance and monitoring.

In attachment to this report we can find several of the questionnaires that were filled by the project partners (See Annexes D02 of this report).

The questionnaires were built to give direct responses, in an objective way. This way, misunderstandings were avoided. There was an effort to build the questionnaire form, in a way that it would be:

- Simple.
- Easy and inviting to fill out.
- Inviting to ask questions that call for a check of alternative answers, a yes or no answer or one word or a few words to complete.
- With all the relevant questions that would give the pretended information.
- With small pieces of information per question.

And,

- Exhaustive Internet research related to Wind Energy European and National laws, Standards, specifications and requirements.

All the information collected by conduction of Internet research was summarised in several tables that explain the state-of-art of Wind Energy European and National laws, standards, specifications and requirements (see in D05, the pages 9 to 30 of the document “PREWIND Certification Requirements Document”).

The objective proposed by the second sub-task was the “Identification of the necessary steps and information to certify the final PREWIND Methodology”. This was possible to achieve by performing the following actions:

- Research about existing specifications and requirements for certification of Wind Energy systems.

Several documents from certification entities were desiccated, with existing quality requirements and specification from the Wind Energy sector. As result of this research we gained valuable information about EU Wind Energy certification standards (see in D05, pages 25 to 30 of the document “PREWIND Certification Requirements Document”).

And

- Interviews to certification entities;

Different authorities and certification bodies were contacted with the objective of collecting more information about certification procedures for PREWIND methodology. The main result of this action defines the necessary steps and guidelines for definition the certification process (see in D05, pages 31 to 33 of the document “PREWIND Certification Requirements Document”).

Task A3: Specification of the NDT requirements and heat source(s) (recapitulation of the 1st reporting period)

<u>Analysis of possible complementary inspection techniques for their use in PREWIND</u>:

At the beginning of this task, an exhaustive theoretical study was carried out mostly by Automation Technology, to determine the most suitable inspection techniques for the analysis of wind turbines and their components. The idea was to investigate how suitable these techniques would be for PREWIND, to analyse their potential and if they would be complementary to thermography, so that through a combination of methods, better and more reliable results can be obtained.

During this investigation, a special emphasis was made in the inspection of the rotor blades, and the practicability of the measurements in this important component was analysed. Following a short description of the technologies studied:

- Ultrasound;
- X-Rays;
- Photogrammetry;
- Oscillation-analysis.

<u>Ultrasound:</u>

Ultrasound is an imaging technique that uses high frequency sound waves and their echoes. The technique is similar to the echolocation used by bats, whales and dolphins, as well as SONAR used by submarines. In ultrasound, the following events happen:

1. The ultrasound machine transmits high-frequency (1 to 5 megahertz) sound pulses into the analysed object using a probe.
2. The sound waves travel into the analysed object and hit a boundary between the different elements of its inner structure.

3. Some of the sound waves get reflected back to the probe, while some travel on further until they reach another boundary and get reflected.
4. The reflected waves are picked up by the probe and relayed to the machine.
5. The machine calculates the distance from the probe to the boundaries using the speed of sound in the element being analysed and the time of the each echo's return (usually on the order of millionths of a second).
6. The machine displays the distances and intensities of the echoes on the screen, forming a two dimensional image.

For the rotor blade inspection, the following conclusions were made, eliminating the use of this technology for PREWIND (an ultrasound-system has a price ranging from € 20 – € 80 thousand):

- The measurements can cover only small areas at a time, so it would be very time consuming to inspect a complete rotor blade.
- The measurements cannot be made contact-free, so it would be very inappropriate for the inspection of the rotor blades when they are mounted in the nacelle (they would need to be dismounted).
- The resulting images are very difficult to be interpreted, so this technique requires a specialist to perform the measurements and analyse the results.

<u>X-Rays:</u>

X-Rays, as well as light, microwaves, TV and radio transmissions, are different kinds of electromagnetic waves. They are all the same kind of wavy-disturbance that repeats itself over a distance called the wavelength. The principle of an X-Ray-equipment is really very simple. Inside the machine is an X-Ray tube. An electron gun inside the tube shoots high energy electrons at a target made of heavy atoms, such as tungsten. X-Rays come out because of atomic processes induced by the energetic electrons shot at the target. Even though through X-Rays it would be possible to look inside of the rotor blades, the following arguments discard this technique for its use in PREWIND:

- The rotor blades would need to be lowered down from the nacelle for being inspected.
- Only small areas can be inspected at a time, so its use in big blades would be very time-consuming.
- Because of the X-Rays radiation, the main disadvantage of this technique is the danger it represents.
- An X-Rays-unit able to measure a blade a cost around € 1 million.

<u>Photogrammetry</u>:

Photogrammetry is an extremely accurate technique of measuring objects (2D or 3D) from photo-grammes (a photographs or images stored electronically on tape or disk taken by video or CCD cameras or radiation sensors such as scanners). The results can be:

- coordinates of the required object-points;
- topographical and thematical maps;
- and rectified photographs (orthophoto).

Its' most important feature is the fact, that the objects are measured without being touched[3]. Principally, photogrammetry can be divided into:

1. Depending on the lens-setting:
   - Far range photogrammetry (with camera distance setting to indefinite), and
   - Close range photogrammetry (with camera distance settings to finite values).
2. Another grouping can be
   - Aerial photogrammetry (which is mostly far range photogrammetry), and
   - Terrestrial Photogrammetry (mostly close range photogrammetry).

The applications of photogrammetry are widely spread. Principally, it is utilized for object interpretation (What is it? Type? Quality? Quantity) and object measurement (Where is it? Form? Size?). Aerial photogrammetry is mainly used to produce topographical or thematical maps and digital terrain models.

Very sophisticated photogrammetry equipments (price: about €. 100 thousand) can be used for Non-Destructive Testing, enabling through a detailed scanning of a surface, the detection of non conformities in the inner structure, such as cavities, etc.. This equipments are however, mainly for their use at a laboratory scale, thus the environment in which the measurements are done has to be disturbance-free. Special measuring benches have to be used to assure a vibration-free measurement, and the most suitable positioning of the object being inspected. The operators need to be very experienced, to be able to interpret the measuring results. Therefore, the use of this technique for the analysis of rotor blades can be discarded.

Oscillation-analysis:

This method uses the normal oscillation generated by the equipment being inspected during its normal operation (the measurement is running all the time). For the rough analysis of the oscillation of equipment, it is common to use different averaged band-with parameters that can indicate a series of causes for possible failures. The two mail values used are the Peak-value and the Root-Mean-Square-value (RMS). Changes in the "normal" oscillation frequencies indicate a "possible" non-conformity.

Automation Technology has had contact with a company developing this type of equipments for the wind energy sector. The personnel of Automation Technology believes that this technique could have a future in combination with PREWIND, because through the oscillation-analysis it would be possible to determine when a thermographic inspection is to be carried out in a more accurate way.

The oscillation analysis method is not a competitor to thermography, but more a supporting complement. Through the oscillation analysis, it is possible to detect the presence of a non-conformity, however its exact location cannot be determined. When analysing rotor blades using this technique, it would is possible only to say if a failure is for example, in the middle of the rotor blade, or near to the end of the blade, etc.. And so, the PREWIND inspection could focus only on this area providing a detailed image of the problem, saving valuable inspection-time.

The Oscillation analysis for wind turbines is however at a very early state, and at this point is still not a reliable technique. Further development need to be done on this method and this will take five to ten years, so that this technology is not to be further considered during the development of this project. The consortium will however follow the advances made in this field, for a possible cooperation in the future.

[3] The term „remote sensing“ is used also instead of „photogrammetry“. „Remote sensing“ is a rather young term, which was originally confined to working with aerial photographs and satellite images. Today, it includes also photogrammetry, although it is still associated rather with „image interpretation“.

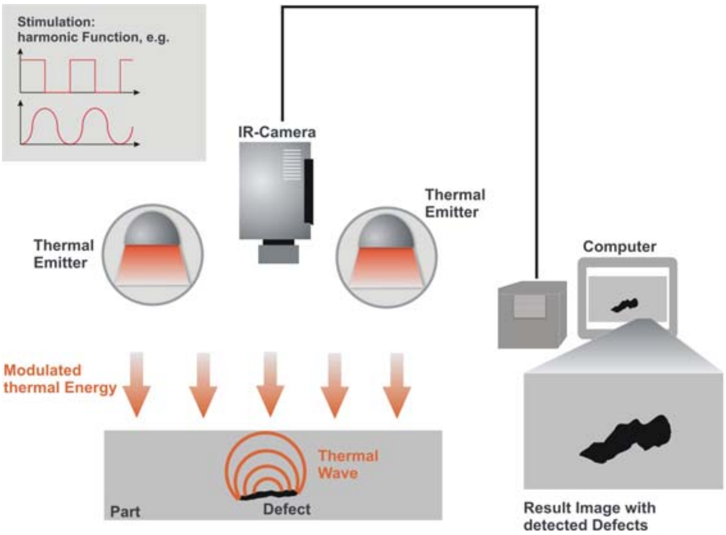
Specification of the NDT-thermographic system for PREWIND:

As it has been commented before, the PREWIND system will comprehend two main systems

- PREWIND Active Thermographic System (for elements that to not emit heat during their normal operation, and therefore a heat source is required to for a thermal excitation: e.g. the rotor blade);
- PREWIND Passive Thermographic System (for elements that do emit heat during their normal operation (e.g. an electrical motor, the E-generator, etc.);

PREWIND Active Thermographic System:

In PREWIND active thermography is used to inspect the GRP or CRP rotor blades for defects like delamination or faults in the bonding of the blade. The measuring principle is shown below:



- **Thermal stimulation of the measuring object with a modulated heat source**
- **Measurement of the thermal response as a function of time with an infrared camera**
- **Signal analysis**

The PREWIND Active thermographic System consist of the following main elements

A) Infrared Camera

B) Heat Source with Power Electronics

C) Computer with Control Electronics

D) IR imaging Software for Active Thermographic Measurements

A) Infrared Camera:

1. The camera must have a Focal Plane Array (FPA) IR detector with at least 320 x 240 pixels (for high quality result images)

   To reduce the effort for inspecting a rotor blade with active thermography, the number of single measurements to cover the whole surface of the blade should be as low as possible. So the system should be able to cover a large area on the blade while giving a good resolution for defects. From this point of view the geometrical resolution of the camera should be as high as possible. On the other hand high resolution infrared cameras are still very expensive. So the resolution of the camera must be a compromise between the price and the ability to perform large area inspections.

Cameras with a detector having 320x240 elements are meanwhile more or less standard in infrared imaging. These cameras are available from many different manufacturers. Because of a growing demand in the market prices are lowering down.

Cameras with a resolution of 640x480 or larger are still very exotic and the prices for this kind of equipment are very high. To use the complete potential of a HighRes detector one would also need a heat source with a very high power output (see chapter below). For quality control in a manufacturing process this may not mean a limitation, but in practical field inspections it may often be not possible, to handle such a big heat source.

LowRes cameras e.g. with 160x120 or 160x128 element detectors have a very attractive price. On the other hand the area on a blade that can be covered with a single measurement may not be sufficient for practical inspections.

Experiments were performed with different camera resolutions to evaluate the area on a blade that can be covered with a measurement. The results are shown in the following table:

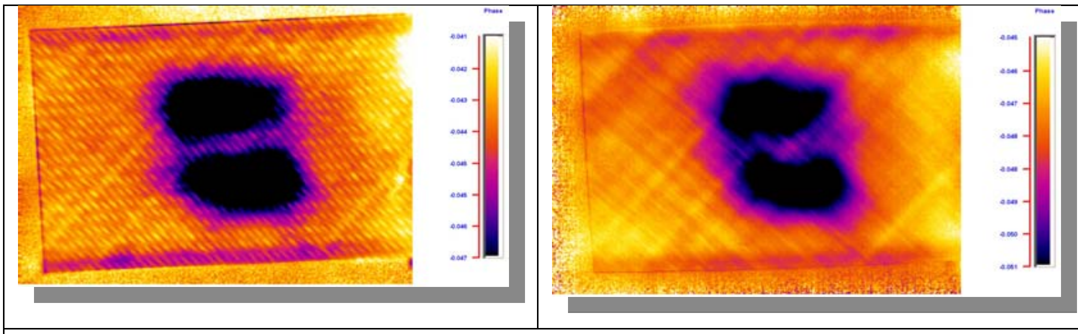
			
Model	ThermaCAM Phoenix	ThermoVision A40	ThermoVision A10
Resolution	640x512	320x240	160x128
Price	> 100 k€	25k€	9k€
Area, that can be covered on a rotor blade	4 – 8 m^2	1 – 2 m^2	0,25 – 0,5 m^2

2. The detector can be cooled or un-cooled

In former times the detector of an infrared camera had to be cooled to very low temperatures. Normally cooling was done with liquid nitrogen, which meant a massive restriction to the practical applicability. In the following years cameras appeared on the market, where the cooling was done with a small Stirling machine. This meant an enhancement for field applications, but the cameras were heavy-weight. Because of the cooler energy consumption was high so that battery driven cameras for field usage had only a short working time. Furthermore the cooler was a wear part which had to be exchanged quite often and with high costs.

A breakthrough for infrared imaging was the introduction of un-cooled micro-bolometer detectors at the beginning of the 21st century. These detectors work without any cooling. They allowed the design of cameras which are small, light-weight and have a low power consumption. Furthermore these cameras have absolutely no wear parts which means, that there are nearly no follow-up costs. Un-cooled cameras are available today with the same detector sizes, as cooled cameras. The thermal resolution, which is an essential parameter for active thermography and which mainly influences the quality of the measuring results is only slightly lower, than with cooled cameras.

Beneath the un-cooled technique also cooled cameras were significantly enhanced in the past years while the costs were reduced. For example with modern cooled cameras the lifetime of the Stirling cooler is about 18.000 to 25.000 hours which means no longer a significant disadvantage compared to un-cooled cameras. The main advantage of cooled cameras remains the better thermal resolution which gives a better contrast in the result images and which is essential to detect defects in large material depths. The main disadvantage is still the high price.



Detection of delamination in a CRP sheet.

Left: Result image from a measurement with a cooled camera

Right: Result image from a measurement with an un-cooled camera

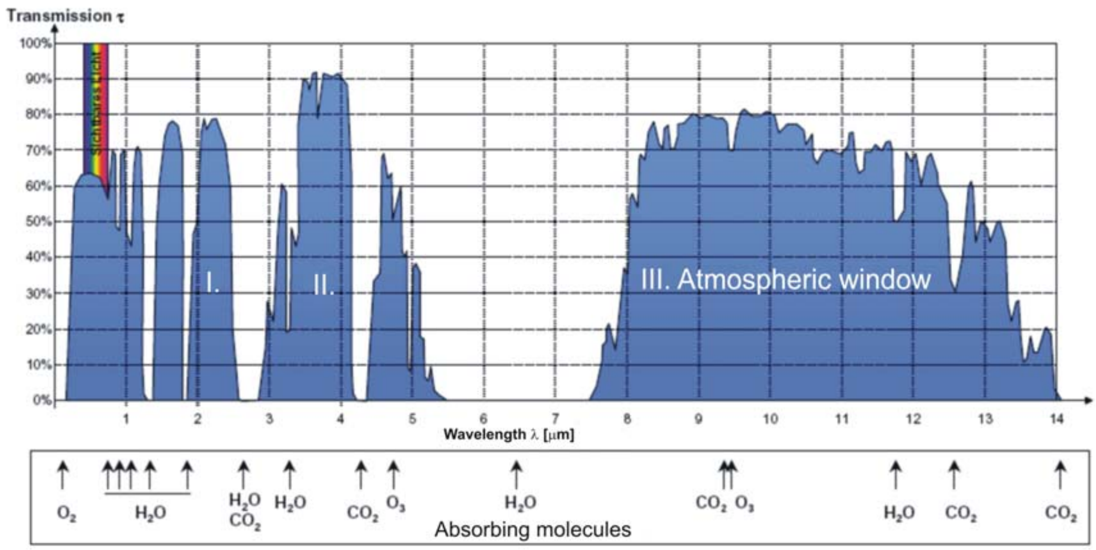
In the following table the main advantages and disadvantages of cooled and un-cooled cameras with respect to the PREWIND project are listed:

Feature	Un-cooled cameras	Cooled cameras
Cooler lifetime and price for exchange	No cooler (+)	18.000 – 25.000 h (0) 10 – 15 k€
Weight	< 120 g to 1,5 kg (+)	3 – 6 kg (-)
Power consumption	< 1,5 W to 6 W (+)	15 – 30 W (-)
Size	Very small (35 x 37 x 49 mm) to moderate (297 x 200 x 109 mm) (+)	Moderate (220 x 135 x 135 mm) to large (340 x 140 x 220 mm) -(-)
Thermal resolution	0,05 – 0,1 K (0)	18 – 25 mK (+)
Contrast of result images with active thermography	Moderate (0)	Good (+)
Depth resolution for defects	Moderate (0)	Good (+)
Price	20 – 30 k€ (+)	50 - > 100 k€ (-)

As a summary the decision between cooled and un-cooled camera technique mainly depends on the application. If it is absolutely essential get an optimum contrast and to detect even small defects in large material depths then a cooled camera should be the choice. In all other cases an un-cooled camera with its various advantages should give results with a sufficient quality. Especially cameras with the new “HS” detectors are a good compromise. “HS” stands for High Sensitivity. This new un-cooled detector generation was introduced in 2005. It offers a thermal sensitivity of 0,05 K (compared to 0,1 K with un-cooled cameras available up to now) and therefore significantly enhances the contrast of the result images with active thermography.

3. The camera can work in the spectral ranges from 2µm to 5µm or from 7,5µm to 13µm [short wave (SW) or long wave (LW) respectively];

Infrared cameras available today are designed to detect infrared radiation in two different wavelength bands: 2µm to 5µm (SW) or 7,5µm to 13µm (LW). The reason is that in these two wavelength bands we have so called atmospheric windows. That means that the gases in the atmosphere have a minimum infrared absorption. The atmospheric windows are essential, if you use infrared cameras to measure absolute object temperatures over large distances (several hundred meters). For measurements with active thermography these windows are not important because you measure no absolute temperatures and measurements are normally performed with small object distances. The performance of cameras for both wavelength bands is comparable, but there is one difference: For the SW-band only cooled cameras are available.



4. The camera can have auto-focus or manual focus

In practical measurements an auto-focus function gives more comfort. On the other hand the condition for a well performing auto-focus is, that you have edges within the image. This will often not be the case during measurements on the smooth surface of rotor blades. So the camera must have a function to switch of the auto-focus and to override it with a manual focus. The manual focus should be motor-driven and controlled by the software. A focus that must be adjusted by hand is not acceptable because in practical measurements the camera will often be arranged in positions where this is not possible.

5. The camera must have a digital interface (IEEE 1394 FireWire, Gigabit Ethernet or high speed serial link), to communicate with the computer and with the analysis software. Digital image data must have a resolution of at least 14 Bit.

With active thermography you record an image sequence representing the temperature distribution as a function of time at the surface of the measuring object during stimulation with a modulated heat source. This image sequence is then mathematically analyzed to get a result image which shows the inner structure of the measuring object. To apply the measuring method, the camera must be equipped with a digital interface, which fulfils the following requirements:

- High bandwidth to transfer the digital image data to the computer in real-time (50 / 60 frames/s).
- Resolution of the digital images at least 14 Bit. During the heating up and cooling down of the measuring object the temperature must be recorded with a high thermal resolution. A resolution 14 Bit (or better) is required to get good results.

Meanwhile many cameras on the market are equipped with standard interfaces (IEEE 1394 or Gigabit-Ethernet), which fulfil these requirements and which make connection to a computer easy. Beneath that some manufacturers have developed special interfaces (high speed serial link) for their cameras.

6. The camera must be able to operate with 110/220 VAC, 50/60Hz. Alternatively the camera should be able to operate with batteries.

This requirement results from the different standards for electrical power in the countries of the world. A camera for PREWIND should be applicable everywhere, independent from the electrical standards. It would be even better, if the camera could be operated alternatively with batteries, because this would give a higher degree of flexibility for field measurements

7. The camera must have an operating temperature range of -15 ^{o} C to +70 ^{o} C and humidity range from 10% to 95%

Requirement results from the expected harsh conditions in field measurements

8. The camera must have a shock protection grade of 25G of higher and vibration grade of 2G or higher

Requirement results from the expected harsh conditions in field measurements

9. The camera must have a tripod mounting: ¼" – 20

The camera should be equipped with a standard mount for fixing it (for cameras this is a ¼" mount). This gives the opportunity, that standard clamps and holders can be used to fix the camera.

10. The weight should be less than 3 kg.

The weight of the camera is one essential factor for field measurements when the equipment must be handled under difficult conditions in large heights. Therefore the weight should be low. With un-cooled infrared cameras this requirement is normally no problem, because they are light-weight. But with cooled cameras the weight should be one parameter for choosing the right equipment.

Imaging performance

11. The camera must have a minimum field of view of 24^{o} x 18^{o}

For field measurements with active thermography on rotor blades the object distance (distance from the camera to the blade) will normally be limited to a maximum of 2 – 3 meters. One reason is that for the measurements the equipment will be fixed to a basket used by wind-turbines maintenance personnel, which allows no larger distances. Furthermore you can not exceed the distance between the heat source and the blade too much without reducing the thermal energy brought into the blade to a limit, where you get no longer good results. This also sets a limit for the distance between camera and blade.

On the other hand the area covered with one measurement should be large to reduce the effort for the complete inspection of a blade. With a 24° x 18° lens the field of view (area covered by the image on the blade) at a distance of 3 meters will be 1,27 x 0,95 m which gives around 1,2 m^2. Lenses with a smaller viewing angle would further reduce the inspected area which might be not acceptable for practical measurements.

12. The camera must have a thermal sensitivity of at least 0.1 °K

The thermal sensitivity is an essential parameter for the quality of the results that can be achieved with active thermography. The better it is, the better will be the contrast in the result image. The thermal sensitivity describes the minimum temperature difference, which can be resolved by the camera. This is the temperature difference that causes a signal which is equal to the noise of the detector and the camera electronics.

If one considers the fact, that during a measurement the temperature amplitude at the surface of a blade is only a few K, the importance of a good thermal sensitivity becomes evident. A high sensitivity leads to less noise in the recorded image sequence which in consequence gives a high contrast result.

13. As an accessory wide angle lenses (45° x 34° / 0.1m or higher) must be available for the camera.

The importance to cover a large object area with the infrared image at small distances was described in 11. In many measuring situations the only way to enlarge the object area covered by a measurement will be the application of a wide angle lens. Therefore such lenses should be available for the camera

<u>Measurement</u>

14. The camera must have an image repetition frequency of 50 Hz or higher (enabling the possibility of taking IR-image sequences)

In order to cover the temperature behaviour during a measurement with a sufficient temporal resolution the camera should deliver digital images with a real-time frame rate of 50Hz or higher.

Additional features like a good spatial resolution or functions for accurate measurements of absolute object temperatures are not necessary for active thermographic measurements in the PREWIND project. Indeed these features are of importance if the camera will be also used for passive inspections. They are described later.

B) Heat source with Power Electronics:

15. The heat source must have a power of 10kW or higher

Because of the thermo-physical properties especially of GRP and the partially large wall thicknesses of a rotor blade a high power heat source is required to generate sufficiently high temperature amplitudes for active thermographic measurements. In addition the paint at the surface is reflective. This means, that with thermal emitters only a part of the radiated energy is absorbed by the blade. So with thermal emitters the power of the source must be even higher.

Experiments were performed to define the minimum power of a source consisting of thermal emitters to cover an area of 1 m^2 with one measurement. The experiments showed, that the required power is between 10 and 12 kW.

16. The heat source can consist of any thermal emitter (IR-lamp, halogen lamp, etc.)

During the project experiments with different heat sources were performed to find out which kind of source is best suited to fulfil the PREWIND requirements. It was found out, that a source consisting of thermal emitters has the most advantages: moderate costs, easy to operate, easy adaptation to different power requirements by adding or removing emitters, good homogeneity of the power distribution over the area covered by the measurement.

To build up the source thermal emitters like IR-lamps or halogen lamps can be used. These emitters give the same good performance for the measurements.

Example for the design of a heat source with thermal emitters
Total power 16kW, 16 halogen lamps, each 1kW, arranged in 4 groups with 4 lamps, completely installed in a stainless steel framework. Each group can be adjusted individually.

17. The heat source must have an electronics device for modulating the power

The principle of active thermography is based on the stimulation of the measuring object with harmonically modulated thermal energy. The frequency, amplitude offset and waveform of the modulation must be adjustable.

For a heat source consisting of thermal emitters the modulation can be performed with an electronics device containing a thyristor-controller. The thyristor-controller must be able to handle the high electrical power for the source. The complete electronics device must have an analogue or digital interface so that the measurement parameters (frequency, amplitude, offset, and waveform) can be adjusted by the control electronics and the software in the computer of the measuring system.

18. The heat source must be powered using a standard 32A outlet

19. The heat source must have a fixing mechanism (to be fixed to a basket used by wind-turbines maintenance personnel)

20. the heat source must also allow to be fixed to a normal stand for measurements made at ground level

C) Computer with Control Electronics

Depending on the camera model that is used within the measuring system, the data rate of thermal image data from the camera to the computer is between 8 – 32 MByte/s. One measurement can contain an image sequence consisting of several thousand single images. This means a total data amount of several hundred MByte, which must be analyzed with complex software algorithms to calculate the result image. For data handling and analysis the requirements to the system computer are quite high. They are listed below:

20. The computer must be portable (no desktop)

Because of the requirement to use the PREWIND system for field measurements, the computer must be portable. Standard devices like notebooks are not acceptable. They are designed for office use and will not withstand conditions in field measurements. A good choice are Portable Industrial PCs. Their very rugged design is for outdoor use under harsh conditions. It fulfils high standards up to MIL. Normally these computers are equipped with standard motherboards, so that there are no compatibility problems to other devices.

Portable Industrial PC for field measurements under harsh conditions

21. The computer must have a Pentium 4 CPU, 1 GB RAM, 2.66 GHz or higher

22. The computer must be able to communicate with the IR-camera.

Depending on the camera it must have a IEEE 1394 digital interface (FireWire), a Gigabit-Ethernet interface or it must be equipped with a special interface for high speed serial link.

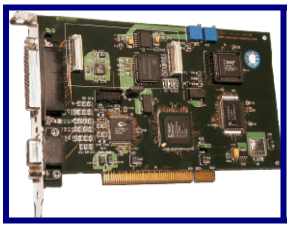
23. The computer must have sufficient storage capacity for the IR-sequences

A hard disc with a storage capacity >100 GByte is recommended. The computer should be equipped with a fast DVD writer for data saving.

24. The computer must be able to operate with 110/220 VAC, 50/60Hz

25. The computer must be equipped with a control electronics

For controlling the power electronics of the heat source the computer must be equipped with a special electronics device. It forms a functional unit with the IR-imaging software: During a measurement commands are generated and send to the power electronics to control the heat source according to the settings in the software (frequency, amplitude, offset, waveform). Normally the electronics device will be a special board assembled in the computer, with an analogue or digital interface for communication with the power electronics.



Example for the design of the control electronics

D) **IR-imaging software for active thermographic measurements**

The heart of the system is the software for active thermographic measurements. It must have the following functions:

- Interfacing to the camera. Control of all camera functions (e.g. focus, measurement range, frame rate, noise reduction). The software should be able to operate different camera models, so that the camera can be chosen according to the measuring task.
- Control of the heat source with power electronics (frequency, amplitude, offset, waveform)
- Synchronization of camera and heat source during the measurement
- Grabbing of infrared image sequences in real time with the full frame rate of the connected camera or with an adjustable frame rate
- Analysis of the recorded thermal image sequences with different algorithms to calculate the result image
- Storage of all settings for measurement and analysis as workspace files for easy operation

PREWIND Passive Thermographic System:

Application: inspection of *electrical equipment* of wind turbines (electrical cabinets, transformer, electrical connections, electrical motors, etc.) and *moving / rotating parts* (generator, coupling and brakes, drive shaft, etc.).

The PREWIND Passive thermographic System consists of a portable Infrared Camera (hand-held). It is used to measure temperatures on the electrical installations and the moving mechanical parts of a wind turbine and to detect local overheating (hot spots) which are indicating defects. The camera must fulfil certain requirements, which are listed below. The importance of most of these requirements was explained for the active system. These explanations are not repeated here.

1. The camera must have a Focal Plane Array (FPA) IR detector with at least 160 x 120 pixels;

The camera is used to measure temperature distributions. As a hand-held system it is moved during the measurements to inspect the whole surface of an object. Therefore the requirements regarding the geometrical resolution are not as high, as for the active system. A detector with 160x120 elements (more than 19000 measuring points) is sufficient for this task.

2. The detector can be cooled or un-cooled;

3. The camera can work in the spectral ranges from 2µm to 5µm or from 7,5µm to 13µm [short wave (SW) or long wave (LW) respectively];

4. The camera can have auto-focus or manual focus;

5. The camera must have a IEEE 1394 digital output (FireWire) or a standard RJ-45 Ethernet connection, to communicate with the computer and with the analysis software;

6. The camera must be able to operate with 110/220 VAC, 50/60Hz or with batteries (with an operating autonomy of more than 1 hour);

7. The camera must have an operating temperature range of -15 ^{o} C to +70 ^{o} C and humidity range from 10% to 95%;

8. The camera must have an encapsulation with a protection grade of IP40 or higher;

9. The camera must have a shock protection grade of 25G of higher and vibration grade of 2G or higher;

10. The camera can have a tripod mounting: ¼" – 20;

11. The must weight under 1,5 Kg.;

12. The camera must be able to save the infrared images directly into a portable computer (laptop) or into a memory card with a capacity of 10MB or higher;

13. It must be possible to analyse the IR-images through an image processing software (for the set of measuring points, the use of temperature profiles, isotherms, etc.).

Imaging performance

14. The camera must have a minimum field of view of 24^o x 18^o;

15. The camera must have a thermal sensitivity of at least 0.1 ^{o}K;

16. The camera must have a minimum spatial resolution of 1.3 mrad;

The spatial resolution (IFOV = Instantaneous Field of View) describes the ability of an infrared camera to resolve small objects or objects at large distances. If in the infrared image an object covers less than one pixel, the temperature reading for this object will be wrong. With a better spatial resolution smaller objects cover one pixel and the temperature can be measured. For example with an IFOV of 1.3 mrad and at a distance of 4 meters the smallest object that can be measured must have a size of at least 5.2 x 5.2 mm (minsize = 4m x 1,3mrad = 5.2mm). The spatial resolution outlined in the datasheets of infrared cameras is an ideal value. In practice there are chromatic and spheric aberrations of the optics and the real resolution that can be achieved is typically between 3 to 5 times worse than the spatial resolution. This can be described by a factor f_{Optics}. Example IFOV = 1.3 mrad, distance = 4 meters, f_{Optics} = 3: minsize = 4m x 1.3mrad x 3 = 15.6mm. So for this example the minimum size of an object must be 15.6 x 15.6 mm to get an accurate reading for the temperature.

17. The camera must have exchangeable lenses (ranging at least between 16^o and 45^o).

The camera must offer a very high flexibility to adapt it to different sizes of measuring objects and different object distances. For infrared cameras there are no zoom lenses available. Therefore the camera must have a set of lenses ranging from tele to wide-angle.

Measurement

18. The camera must measure in a temperature range from –40 ^{o} C to +400 ^{o} C;

19. The camera must have an accuracy of ±2 ^{o} C or ± 2%;

For passive inspections on wind turbines the camera must be able to measure absolute temperatures. Infrared cameras measure the infrared radiation coming from an object. This radiation is in a direct correlation to the temperature of the object, which is described by the physical laws from Planck and Stefan-Boltzmann. So by measuring the radiation coming from an object one can directly calculate its temperature. In practice the detector and the electronics of a camera have an individual characteristic, so that the basic physical laws must be adapted by some parameters that are individual for each camera. These parameters are determined during a calibration process. The better the calibration is performed, the higher will be the accuracy of the camera. Here are differences between the camera manufacturers.

20. The camera must allow individual emissivity setting (0.1 to 1.0) ;

The infrared radiation coming from an object is a function of the temperature and the emissivity. The emissivity describes the ability of an object to send out radiation at a certain temperature. It can have values between 0 and 1. The higher the value, the more radiation is coming from an object. For example metal surfaces has a very low emissivity (between 0.01 and 0.1) while bricks or the human skin has an emissivity near to 1. To measure the temperature of an object with an infrared camera, you must adjust the emissivity to the correct value. So the camera must have a function to set individual emissivity values.

21. The camera must allow measurement corrections: reflected ambient, distance, relative humidity, external optics, etc.;

In a real measuring situation some additional conditions have to be considered to get accurate temperature readings: The camera sees not only the direct infrared radiation from an object, but also radiation from the surrounding, which is reflected at the object's surface. On the way from the object to the camera the radiation is partly absorbed by certain gases in the atmosphere (water vapour, carbon dioxide). The atmosphere itself is also an infrared radiator, which must be considered for temperature calculations. Furthermore the components of the camera (e.g. the lens or the body) are infrared radiators and the detector sees also radiation from them.

In most cases modern infrared cameras have functions and settings to compensate these additional effects. A camera for PREWIND must have this functionality.

22. The camera must have an image repetition frequency of 50 Hz or higher (enabling the possibility of taking IR-image sequences).

NOTE: This requirements can be modified if considered necessary during the further research phases of the project.

2.1.3. Deviation from the project work-programme, and corrective actions taken/suggested

As it was mentioned before, there was only a slight delayed in the development of the tasks for the first year, they do not have much significance, because the consortium was able to recover the time lost.

The most considerable difficulty that the consortium had to affront was the desire of two partners to abandon the project: the IAG ISES and the SME partner TEGOPI. Both partners have expressed to the coordinator their intentions to withdraw from the project's consortium.

TEGOPI, due to reorientations of their business strategy was not able to carry out any of the tasks scheduled for them in the work-programme. The main tasks of TEGOPI for the reporting period were to provide the consortium with technical information regarding wind turbines and their failures, especially in the towers, as well as to support the consortium in the analysis of components and in the development of the working methodology. Their tasks where assumed by other partners in the consortium, mostly by Reetec and Krypton, who are also involved in the wind energy business.

The IAG ISES performed well their activities for the first reporting period, but cannot continue working on the project due to a reduction of their staff, which minimizes their capabilities to carry out their tasks in PREWIND. The tasks of ISES during the first period consisted in providing information on the Italian wind energy market for the development of tasks A1 and A2, to support partially the first steps of the development of the working methodology, and to support FGW in the development of the task D1 and D2.

The corrective measures for this issue are to find two replacements for these partners. At this moment, all the documents are being prepared to do an amendment to the project's contract, to make the partner-exchange official.

2.1.4. List of deliverables (recapitulation of the 1st reporting period)

Work package	Del. No.	Deliverable name	Delivery Date	Status	Man-Months planned	Man-Months used
A	D 01	Developed target oriented questionnaire for the collection of information	Month 02	Completed	5,75	5,13
	D 02	Assessment of filled in questionnaires	Month 06	Completed	5,75	5,13
	D 03	Developed parts/components inventory	Month 06	Completed	5,75	5,13
	D 04	Developed technical specifications document	Month 06	Completed	5,75	5,13
	D 05	Developed certification requirements document	Month 06	Completed	10,50	9,38
	D 06	NDT Technological requirements document	Month 06	Completed	5,00	4,46

2.1.5. List of milestones (recapitulation of the 1st reporting period)

With the fulfilment and achievement of the deliverables foreseen for the first work-package, it has been considered to have fully achieved the first milestone of the project.

Workpackage No.	Mileston No.	Milestones	Delivery date (Month)	Staus
A	M1	Initial Specification Complete	6	**Completed**

Work-package B – Development of Working Methodology (including a recapitulation of the 1st & 2nd reporting period)

The following table shows the amount of personnel resources planned for this work-package per participant and the amount used (more detailed information can be found in the Annex 1).

Work Package B: Person Month Table per Partner																	
		IAGs						SMEs						RTDs			
	TOTALS	FGW	APPA	APREN	APER	IWEA	GEAL	Alphatherm	ILIAKO	Reetec	Krypton	EED	Jonica	TTZ	AT	AmbiQual	CRIC
Used	**17,41**	2,33	0,25	0,25	0,00	0,78	0,20	2,69	2,13	0,20	0,60	0,24	1,28	3,28	2,18	0,50	0,50
Planned	***63,75***	*1,75*	*1,25*	*1,25*	*1,75*	*1,75*	*1,75*	*3,75*	*4,25*	*3,25*	*3,25*	*5,25*	*5,25*	*8,00*	*8,25*	*8,00*	*5,00*

2.2.1. Work-package objectives and starting point of work at the beginning of the reporting period

The objective of this work package is to carry out analyses, planning, design, engineering and testing, activities necessary for the development of the working methodology of PREWIND and its components. The working methodology represents an essential part of the final PREWIND Methodology, which includes the development of working procedures and their required templates.

2.2.2. Progress towards objective

Task B1: Analysis and Characterisation of parts/components (recapitulation of the 1st reporting period)

Based on the inventory carried out in the task A1 the identified parts/components will be analysed by TTZ with support of Alphatherm and CRIC according to the different characteristics, including its material composition, physical dimensions and the type of defects to be monitored. To each part/component a code (to be designed in this task by TTZ in close cooperation with A.T. and CRIC) will be assigned.

From our previous research, we know that nowadays, there are two main philosophies for building wind turbines:

- The ENERCON wind turbines (using a ring generator combined with the rotor hub in a gearless system)
- The rest of the manufacturers using with systems using gearbox

Since the PREWIND methodology has to be applicable to all wind turbines, therefore it has to be kept general, emphasising on the elements that are equal to all wind turbines, independently of their manufacturer.

Based on the inventory carried out in the task A1, the main identified parts of wind turbines where will be analysed, and a code-system was developed, to identify the different components according to their characteristics, including its material composition and location in the wind turbine.

This code will also separate the parts/components in two main categories: *active* and *passive,* according to their ability to be tested by Non-Destructive-Technologies.

To the *passive* group will belong all those parts/components that for their analysis do not require the use of an external heat source, e.g. parts/components that store internal energy and/or are capable of radiating thermal signals and therefore do not need external excitation. To this group belong for example: the disc brake, electrical components (circuit breakers, connectors), etc.

To the *active* group belong all those components that for their analysis require the use of external heat sources to induce energy into them and thereby characterize defects on a more qualitative basis such as: the rotor blades, the nacelle, etc..

The following Table 1 summarizes the main parts / components of wind turbines, pointing out their check-type and tests-points, as well as the approximate periodicity in which each component has to be monitored.

The procedure for the development of the code for the components can be found in the annex D07 of this report.

Nr	Code	Components	Check-type and Test-points	Test Intervals			comments
				Yearly	Every 2 years	Every 4 years	
1	A-G-R--HUB	**Hub** (die Nabe)	ruptures, corrosion, coat of paint	From 1500kW	300 till <1500kW	<300 kW	to be inspected using active thermography
2	P-M-N--LSH	**Low speed shaft** (Antriebswelle langsame Seite)	ruptures, corrosion, coat of paint, tension pully	From 1500kW	300 till <1500kW	<300 kW	to be inspected using passive thermography
3	P-M-N--SRW	**Screw fastening from drive shaft to hub assembly** (Schraubverbindung Welle-Nabe)	ruptures, corrosion, starting torque, tractive force of a relay	From 1500kW	300 till <1500kW	<300 kW	to be inspected using passive thermography
4	P-M-N--API	**Axial pivot** (Achszapfen)	ruptures, coat of paint	From 1500kW	300 till <1500kW	<300 kW	to be inspected using passive thermography
5	P-M-N--RBE	**Rotor bearing** (Rotorlager)	Impermeability, sound, friction, temperature, lubrication, screw fastenings, lightning protector, etc.	From 1500kW	300 till <1500kW	<300 kW	to be inspected using passive thermography
6	P-M-N--GBX	**Gearbox** (Getriebe)	Sound, heat development, abrasion of the gearing, corrosion, attrition	From 1500kW	300 till <1500kW	<300 kW	to be inspected using passive thermography
7	P-M-N--DSY	**Complete drive system** (Gesamter Antriebstrang)	Vibration test	From 1500kW	300 till <1500kW	<300 kW	to be inspected using passive thermography
8	P-O-N--OSY	**Oiling system** (Ölversorgung)	General condition, function check and impermeability	From 1500kW	300 till <1500kW	<300 kW	to be inspected using passive thermography
9	P-O-N--HSY	**hydraulic system** (die Hydraulik)	General condition, function check and cooling effect (temperature difference) , foam formation, filter test, oil-pump check, analysis of oil, sound heat exchanger	From 1500kW	300 till <1500kW	<300 kW	to be inspected using passive thermography
10 11	P-M-N--CNG P-M-N--BRK	**Coupling and brake** (Kupplung und Bremse)	Visual control, function check, abrasion and attrition	From 1500kW	300 till <1500kW	<300 kW	to be inspected using passive thermography
12	P-M-N--TSU	**Torque support** (Drehmomentstütze)	Function check rubber mount, movement, etc.	From 1500kW	300 till <1500kW	<300 kW	to be inspected using passive thermography
13	P-M-N--EGN	**Electrical generator (fast rotating) driving-gear-free Wind turbines** (Generator (schnell laufend) getriebelose WEA)	bearing-noise, impermeability (leak tightness), grounding (earthing), anchorage to the maschine-foundation, terminal box, collector ring, wear of friction of the coals, oscilation, adjustments / alignments	From 1500kW	300 till <1500kW	<300 kW	to be inspected using passive thermography
14	P-M-N--EGN	**Electrical generator (slow rotating) driving-gear-free Wind turbines** (Generator (langsam laufend) getriebelose WEA)	Tragkörper untersuchen auf Risse, Korrosion, Luftspalt, Schraubverbindungen, Isolierung	From 1500kW	300 till <1500kW	<300 kW	to be inspected using passive thermography
15	P-M-N--COU	**Cooling unit** (das Kühlaggregat)	function check	Yearly			to be inspected using passive thermography
16	P-M-N--ANM	**Anemometer and wind vane** (Anemometer und Windfahne)	function check	Yearly			to be inspected using passive thermography
17	P-M-N--YME	**Yaw mechanism** (die Windnachführungs-einrichtung)	Sound, abrasion of the gearing, corrosion, attrition	Yearly			to be inspected using passive thermography
18	A-G-N--NAC	**Nacelle** (die Gondel)	ruptures, cracks, ...	Yearly			to be inspected using active thermography
19	P-M-T--TWR	**Tower** (der Turm)	cracks, rust, ...	Yearly			to be inspected using passive thermography
20	P-O-G--TFO	**Tower foundation** (das Turmfundament)	cracks	Yearly			to be inspected using passive thermography
21	P-M-N--TCO	**Temperature control** (Temperaturkontrolle)	Test of maximal working temperatures: - gearings - oil - other moving parts - at the moment a temperature control is not completely possible	From 1500kW	300 till <1500kW	<300 kW	to be inspected using passive thermography
22	P-M-G--TRF	**Transformer** (der Transformator)	false contacts, short circuit between phases, etc.	Yearly			to be inspected using passive thermography
23	P-M-N--ECN P-M-T--ECN P-M-G--ECN	**Electrical connections / pannels** (die Elektroanschlüsse)	false contacts, wearout components, etc.	Yearly			to be inspected using passive thermography
24	P-O-N--ECO P-O-G--ECO	**Electrical controler** (elektronischer Regler)	function check	Yearly			to be inspected using passive thermography
25	A-G-R--RBL	**Rotorblades** (die Rotorblätter)	due to the importance of this components it is showed on a separated page	Yearly			to be inspected using active thermography

Table showing the inventory of the main wind turbine components identified. The yellow column shows the Code developed for the classification of parts, according to their characteristics.

With the support of this code it is intended, to simplify the processing of the data related to the wind turbine inspections: planning of the monitoring activities, analysis of the information generated during the inspections, etc..

Task B2: Development/Adaptation of preventive Maintenance control software (recapitulation of the 1st reporting period)

The first version of the Preventive Maintenance Control Software is finished. The software was completely developed by the TTZ within the PREWIND project, in close cooperation with the partners involved in maintenance of wind turbines.

The main function of this software will be the management of a Database, for the planning/controlling of the maintenance routines of the wind turbines according to the information stored and of different inputs to be determined, such as: working hours of the units, possible defects in the past, season/time of the year, etc. The software must be able to compile measurement reports in a format required for certified working methodologies.

For the development of the software, the personnel responsible for the planning of preventive maintenance activities of wind turbines was interviewed, to assure the functionality of the application developed, on the basis of the PREWIND methodology's features.

Due to the fact that this application was developed completely during the project, by one of the participating RTDs, the 100% of the rights to this software will remain with the participating associations. Because the main goal of this software is to support the proper planning of preventive maintenance works to increase the profitability and safety of wind turbines, which is of interest of all the partners involved, it is foreseen to distribute this software as freeware, as a part of the dissemination strategy for the project's results.

It was decided to use Access as the basis for the programming, since we are dealing with the management of a database, and Access is very popular software that is at hand in most companies. A copy of the application developed can be found in the CD accompanying this report, in the D08. It must be remarked that the database of the version available in the CD is almost empty, containing only a few examples (to protect the privacy of the clients of the project partners).

As commented before, this Software application manages a database, which holds all important data of every maintenance action of a wind turbine, so that the information can be easily accessed by a wind-park administrator, a maintenance company, etc.

30kkkkkThe application includes an alarm message system which points in advance the works to be done in the nearer future and marks tasks with open deadlines in the past (with emphasis in thermographic inspections, also with general maintenance information).

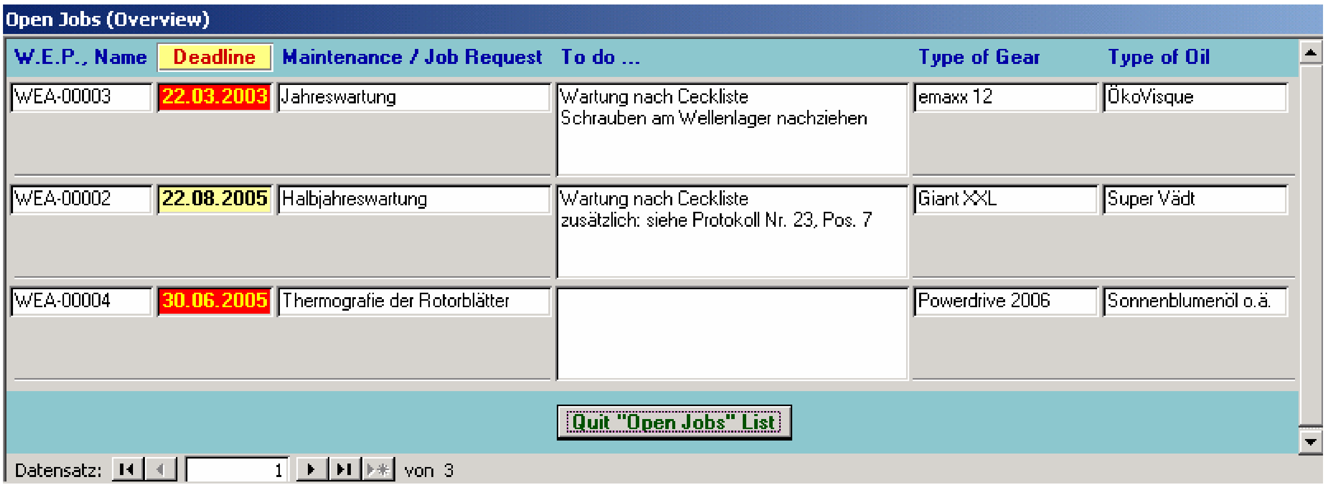


Figure 1: First screen is after starting the database

The administrator of the database fills in new maintenance datasets for the next maintenance tasks, has the overview over the jobs to be done, prints out the job requests for the maintenance technicians, fills in the data of done jobs and gets an overview over the costs of every maintenance service task.

All data of a maintenance service task can be accessed from one data mask, which is divided in several logical parts by a tab-register.

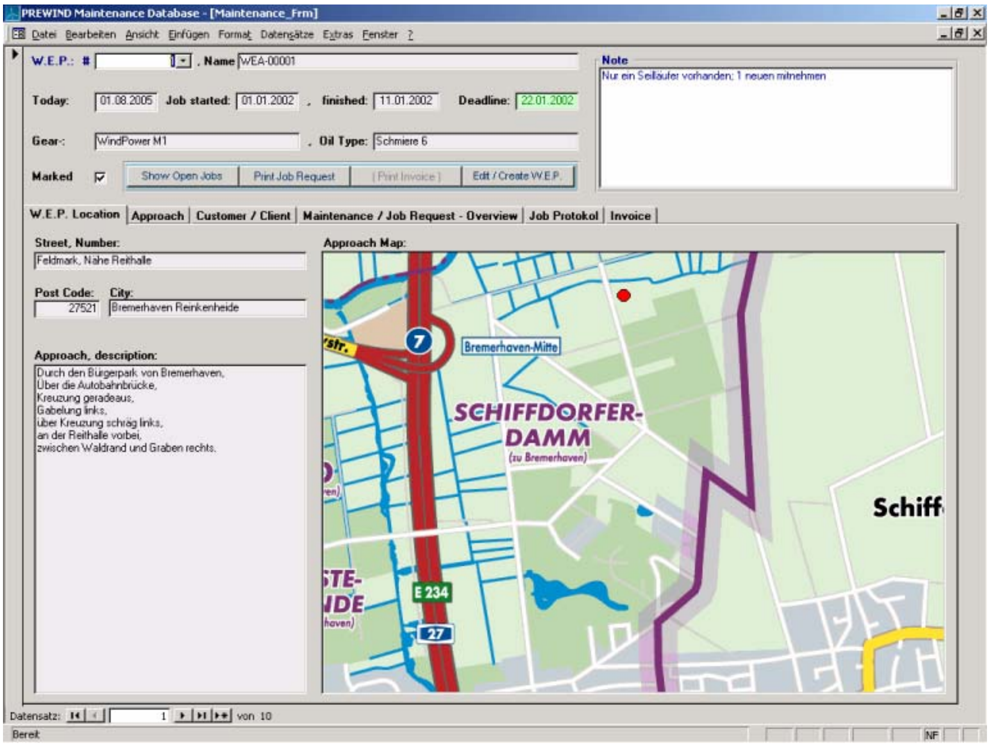


Figure 2: Data set mask with tab register

Some of the tabs contain fields for showing for example an approach map or a sketch of the location, which can help the maintenance personal find the way to the wind turbine, as well as fields for filling in notes about things to keep in mind for jobs to be carried out for a specific wind turbine; things like the contact information of the persons who has the key for opening access barriers, etc..

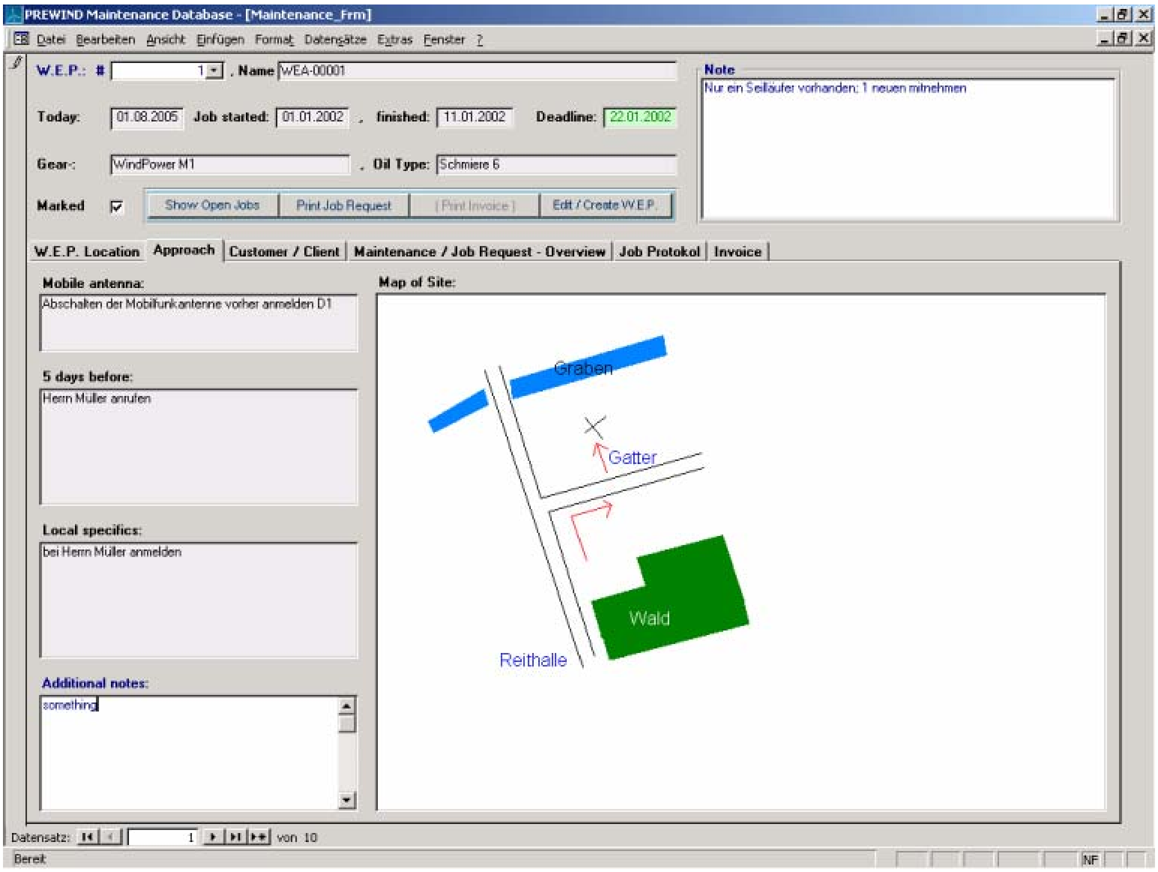


Figure 3: Sketch of approach map of the location, notes regarding the location etc

One of the tabs shows data of the customer, another one is for filling in the general task data like beginning and end of the work, or the deadline of a task. As long as there is no date filled into the field for the end of the work, the task is shown in the list with jobs to be done.

If the date of the deadline is older then the actual date, the background of the cell in the to do list becomes red. If there is a date filled in for the end of the work, the task is shown no longer in the to do list.

There is a tab called "job protocol" for filling in the works to be done for a task and a field for filling in the works which have been done. The administrator of the database can print out a maintenance/job-request, which contains the data of the field with works to be done for the task, deadline, notes regarding the location, etc..

The last tab of the tab register is for filling in general invoice data. It shall give an overview of the financial aspect of the maintenance task.

The SME partners REETEC, Krypton, EED and Jonica, involved in related activities to wind turbines, where asked to provide feedback on additional useful tools for the database. One partner had the idea to include the opportunity of generating a report which contains all financial aspects of all tasks of one customer.

Another idea was to select technical problems of all maintenances/jobs and their solutions in a sub-database. This would be a growing knowledge database with the advantage, that every maintenance technician can give tips to all of his colleagues, and all colleagues can learn from the knowledge of every other colleague. The problem will be to create something like a standardisation of possible technical problems, which makes it possible to search the database with usable results. Regarding the short timeframe of the task for creating the database, we propose to make such a knowledge database part of a future project with the main aspect on expanding the PREWIND maintenance database.

Once the above mentioned partners have finish testing the PREWIND Maintenance Database, with their feedback, the final version will be programmed, and then, a Software manual will be developed.

Task B3: Selection/Adaptation of the NDT techniques and heat source(s) (including a recapitulation of the 2nd reporting period)

As was commented already in the previous report (1st Years Activity Report), the main objective of this task was to select / adapt the NDT technological requirements for PREWIND according to what was defined in task A3. These requirements were determined using the data and experience provided by the partners involved in activities related to thermography, and after performing some laboratory tests and an exhaustive literature and Internet research.

As it has been commented throughout the project, the PREWIND method will comprise two types of thermographic measurements, depending on the component being inspected:

- PREWIND *Active* Thermographic System: for elements that do not produce heat during their normal operation, as for example, the rotor blades.

- PREWIND *Passive* Thermographic System: for every component that produces heat during operation, as for example an electrical motor, a bearing, a disk-brake, etc..

In this section of the report we will focus only in selection of the most suitable heat source for PREWIND (“active thermography”).

During the first year of the project, a number of technicians from the wind energy branch where interviewed with the aim of defining the requirements for the Active thermographic system,. From this task, it was clear that the main defects to be detected in the rotor blades are:

a) superficial failures

b) structural failures

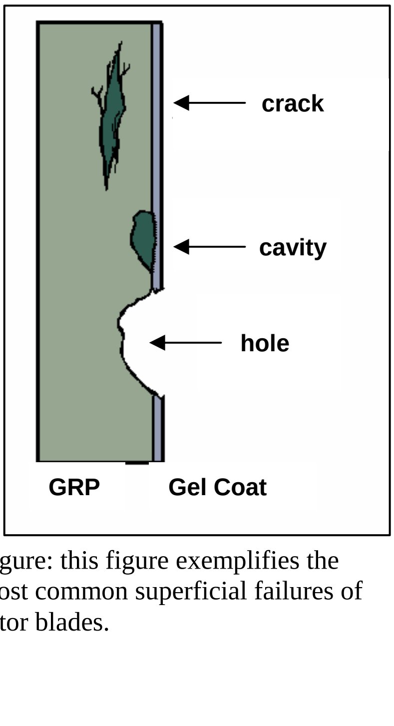


Figure: this figure exemplifies the most common superficial failures of rotor blades.

a) Superficial Failure:

During the production of the GRP walls of the rotors numerous glass fibre mats with epoxy resin are glued together with one another. The mats are put individually, usually by hand, one above the other into a form and stuck together with the resin. If this work is not accomplished extremely carefully, cavities and bad gluing can be produced. The results are bubbles in the material, which are under the gel coat, the highest film of varnish, which can not be recognized then later. During operation the material can become detached and develop holes in the rotor. Or the cavities can fill themselves up with humidity and during the winter months burst. If damage is not fixed it can lead to delamination and such failures attribute to the loss in stability of the blade.

b) Structural Failure.

During the manufacturing f the rotor blades, two shells are produced, which are then put one on top of the other. Internal bracings must be bonded, before the shells are set one over the other. This way, the first edge of the bracing can be glued perfectly, but the second one is glued blindly, so it cannot be visually inspected to check the quality of the binding. The consequence can be failures in the pasted area that by stress caused during normal operation can result in a burst or a breach.

The sooner the failure is recognized, the less the expense the repair will have. When the failure is not found in time, then the condition of the blade worsens with time and the costs for the reparation are higher.

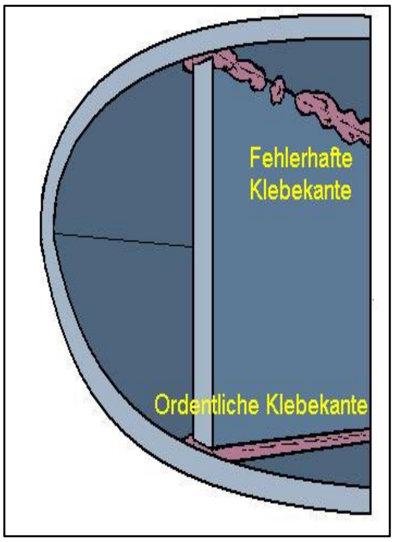


Figure: the figure exemplifies the two edges of a bracing, one is perfectly glued (bottom), and the other not (top). This is one of the most common structural failures of rotor blades

Lab experiments:

For the Active thermography, a “heat” (or “cold”) source had to be determined, to induce a thermal excitation in the test object.

This task was carried out first at a laboratory stage, where many “heat” and “cold” sources were tested on GRP parts of rotor blades. The consortium wanted to compare the results obtained using modulated (computer controlled) heat sources, and not modulated ones.

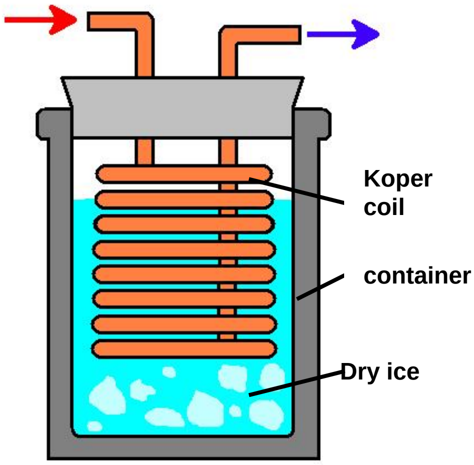
An important aspect that was taken into consideration was the homogeneity of the heat source, since it could lead to misinterpretation of the results.

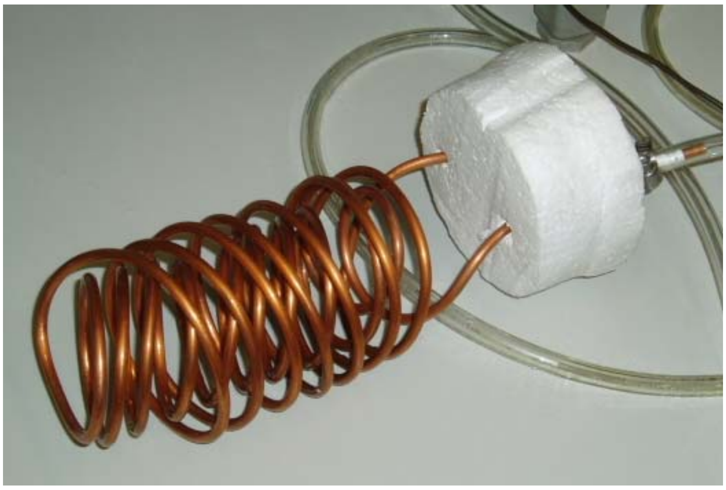
The “heat” (or “cold”) sources tested where:

- Warm air blowers
- Cold air blower
- Infrared emitter
- Halogen lamps

“Cold Source” (not modulated)

For these lab experiments a cooling device was constructed, that “produced” cooled-air. A spiral made with copper tube, with a diameter of 5 mm, and a length of 90 cm (see figures below), that was placed inside of an isolated DEWAR container. The container had a mix of ethyl alcohol and dry ice. The dry ice had a temperature of –78 °C. The cool medium transferred the cold to the cooper spiral. Ethyl alcohol has a freezing point of -114°C and can therefore be well used for this purpose. So, air with normal room temperature was blown on one end of the cupper coil, and came on the other side with a temperature of about 20 degrees below cero.





Picture: Schematic demonstration of the cooling device and picture on the cooling spiral.

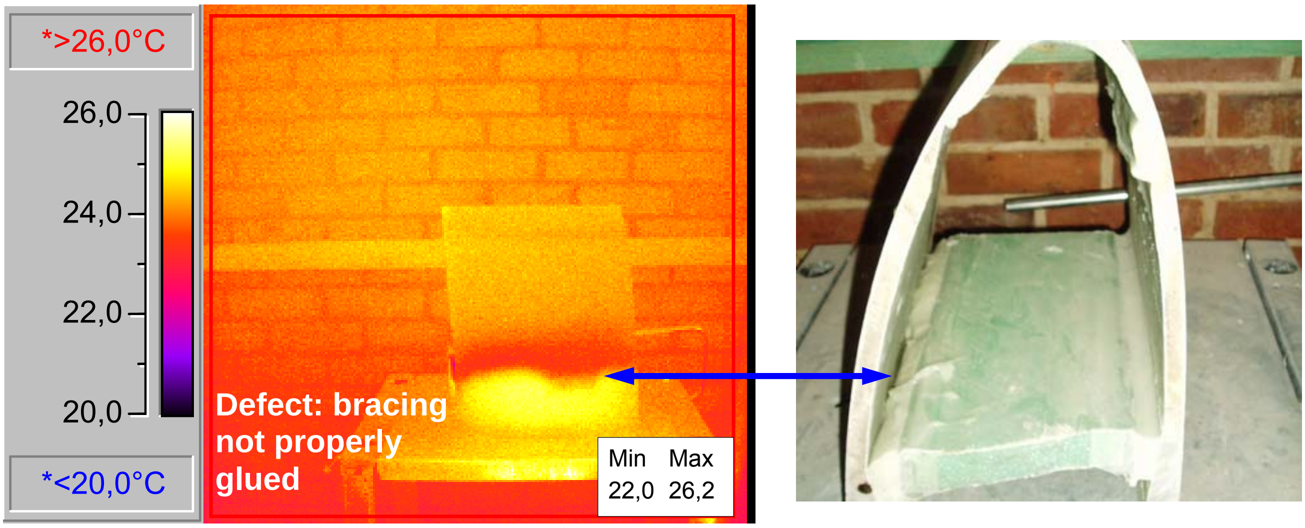


Figure: the IR-pictures shows the penetration of the cool are through the spot with the defect-bonding

By applying the cold air on the inner part of a test sample, the cold flow could penetrate the parts where the binding of the bracing was not properly glued, making this defect visible to the thermographic camera through a temperature contrast.

Heat source: hot air (not modulated):

Similar results could be obtained blowing hot air into the samples. The following pictures where obtained using a heated air blower with 1350 W (air output with 75 °C).

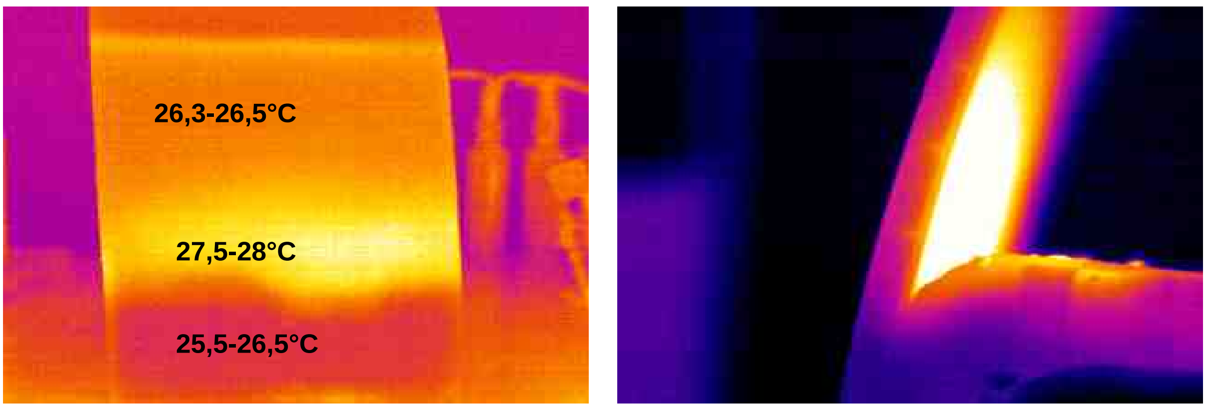
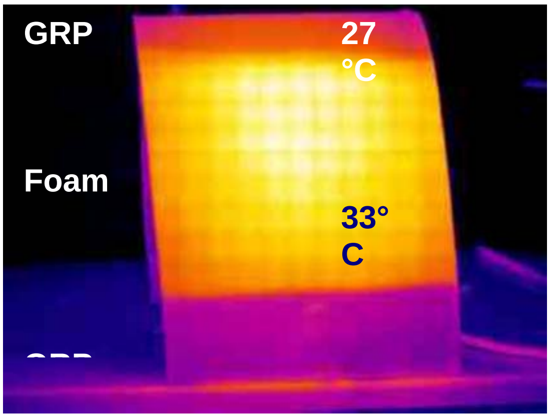
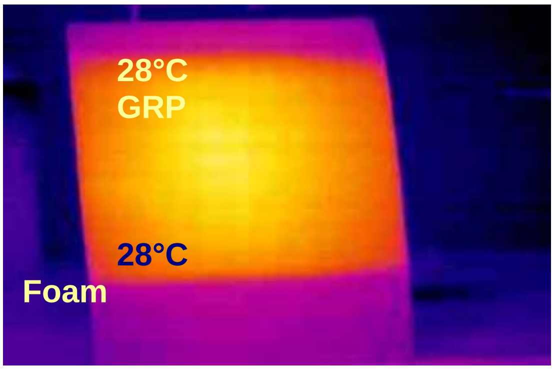


Figure: infrared pictures of the heating of the defect-glued area. The area was heated up with the hot-air blower for two minutes. The glued part is also clearly visible from the outer part. The difference between the inner and outer part is about 10°C and the temperature difference in the surface is 2 - 2,5 °C .

So far it was tried to heat up the components in short periods of time as strongly as possible in order to obtain a high temperature difference. In addition, the heat sources were brought up very near to the test-probes. No sufficient homogeneity was obtained in the heating. In the following attempts the distance of the heat sources was strongly increased, in order to avoid the warming up of only a small area.



Picture: The test sample was warmed up with a hot air blower from a distance of 30cm for 2min. The blower was moved in a circling motion across the sample to achieve a more “homogeneous” heating. The inner structure of the sample is visible.



Picture: In this picture the test-sample was warmed up using an IR emitter from a distance of 50cm (not modulated heat source). The heating of the surface of the sample is relative homogenous.

Experiments on Rotor Blades with Cooling (not modulated).

In the lab experiments it was seen that the errors in thick GRP samples, after the cooling of the material, could be good recognized. For this reason a bigger version of the cooling device was constructed and tested on real rotor blades.

The cooling device was build up from 20m copper tube and a cask. The copper tube, with 20mm diameter, was bent to a spiral and inserted into a plastic barrel with a capacity of 120 L. For a better isolation, the construction was put into another barrel, which was filled of polystyrene. It was cooled with 40 L of ethyl alcohol and 20kg dry ice. The cooling device was attached to a locally existing compressor.

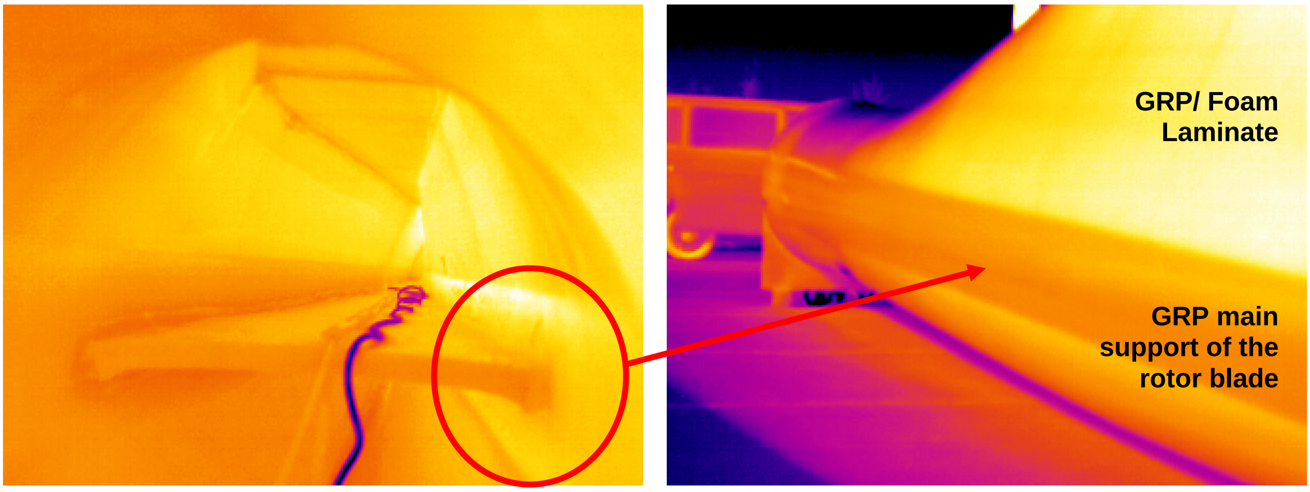
During the construction of the cooling device it was assured that the structure remains “transportable”; the device could be fixed inside of a plastic barrel. The “cold” source was then connected to a conventional compressor, so on one end of the copper tube, air with room temperature would be blown in, and it would come out on the other edge (and after trespassing our built heat exchanger) having a temperature of about minus 70 degrees centigrade.

Figure: digital pictures of the constructed cooling device.

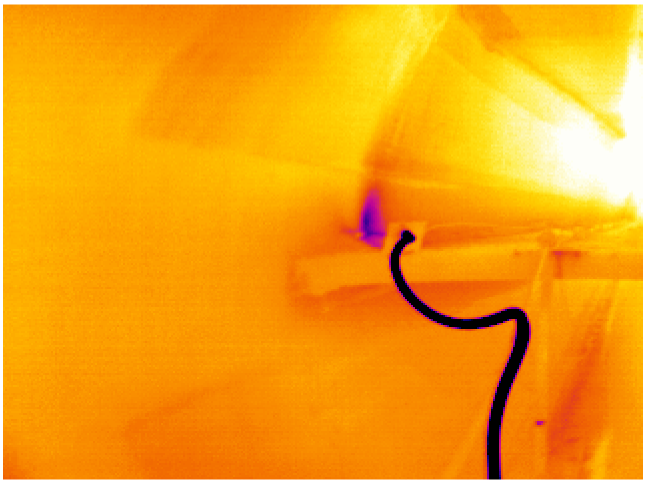
The device produced an air flow with a temperature of about –70 °C cold air, which was then conducted through a hose into the rotor blade. The examined rotor blade had a length of 25m; the hose was located into the centre of the blade.

Picture: Rotor blades in which the experiments were carried out.

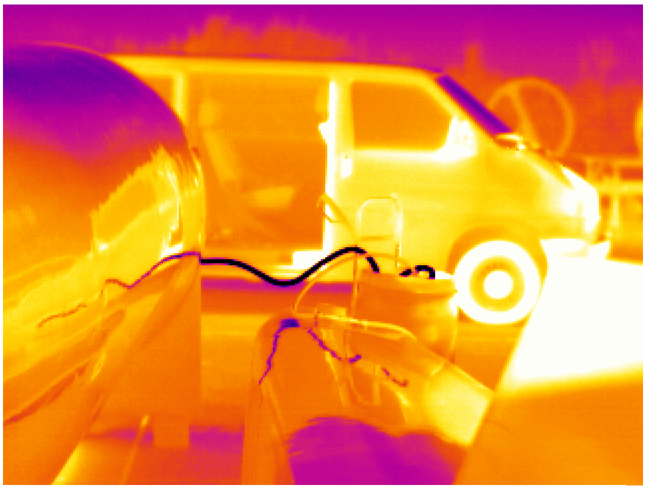
During the experiments the rotor blade laid parallel to two other and in direct sun exposure. For this reason the rotor blade had already a different temperature distribution over the surface. Additionally, there were reflections, which disturbed the analysis performed by the IR-camera.



Picture: Infrared pictures of the rotor.



Picture: Inner part of the rotor. The hose was shortened and led directly on the side panel. The hose had a temp. Of -6 to -10 °C. Material was cooled down from 23°C to 15°C.



Picture: Reflections on the side of the rotor turned away from the sun made a detection of the cooled area impossible.

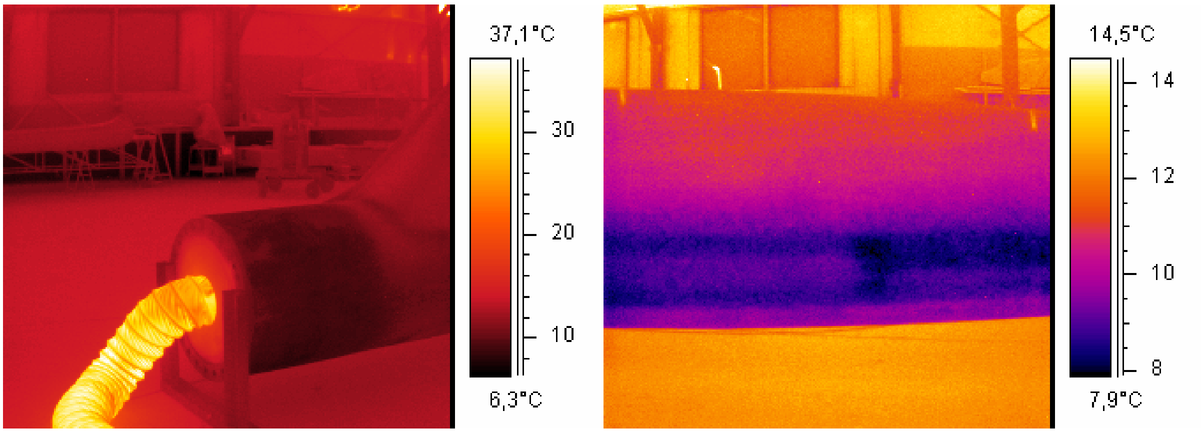
The achievement of the cooling device was too small. After a waiting period of one hour no change in the temperature of the exterior could be determined. For this reason the hose was shortened and led directly in to the wall of the rotor. Also, in this case, after a half hour of waiting no change of the temperature could be recognized with the IR-camera from the outer side.

From this we can conclude that the successful results obtained a the laboratory where not transportable to the rotor blades. The amount of “cooling” power required to achieve sufficient thermal contrast is too high, making this method impracticable for the practical use.

Experiment on rotor blades with hot air blowers.

The same test was repeated using a more powerful device, namely a construction blower blowing hot air into the rotor blade.

Picture: Inspection of a complete rotor blade using a construction blower blowing hot air into the rotor blade.



Again, no significant results where obtained. After a while, the heat trespasses the thick layers of GRP material of the rotor blade, but the over all process takes too long to be practicable in a competitive market.

Results of the inspection of the Rotor blades.

During the investigation of the samples of the rotor blades, within the laboratory framework, promising results were obtained. The main errors, which arise at rotor blades, could be clearly detected through the IR-camera.

These results could only in a very difficult way, be transferred to the tests carried out with rotor blades. On one hand, the thermal energy was either not being “properly” applied, or at least not in the required amount, so that the efforts made to make failures visible failed. On the other hand, being outside of the laboratory (where the environment is controlled), other aspects gain in influence, such as background temperature, wind blowing, etc.. All this aspects that were not present during the laboratory tests, have a strong influence on the test results, having a tremendous negative effect in the repetitiveness of the measurements.

So it can be concluded that the PREWIND system has to use a modulated heat source, confirming the first approach when defining the NTD technological requirements.

In order to obtain repetitive and reliable results from the thermographic analysis, a technique, such as Lock-In thermography has to be applied.

For the further tests carried out mostly during the second year, the consortium used a Lock-In Thermography System that was developed by Automation Technology for the testing of components in the auto-industry. As a heat source a photo studio halogen lamp with 12 kW of power was used.

Figure: halogen lamps heat source used during the first tests with the Lock-In application (12kW)

Figure: electric control (1) for the steering of the modulation of the heat source, and computer (2) with the Lock-In application.

Figure: digital picture of the thermographic camera used for taking the Lock-In images above (FLIR Camera A-40).

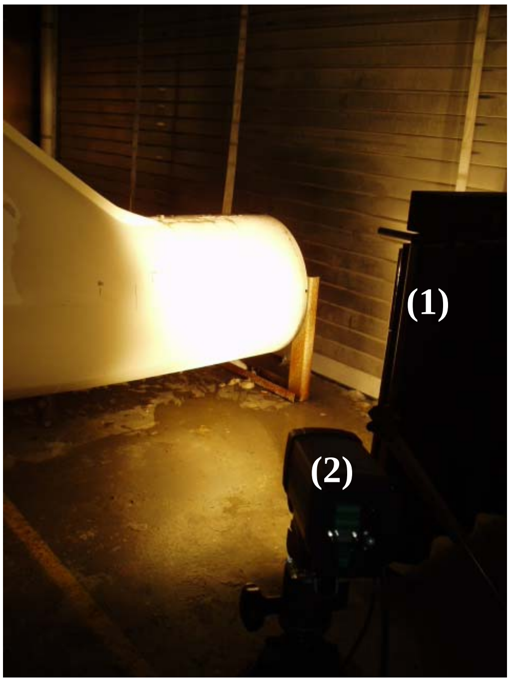


Figure: the heat source (1) in action during one of the Lock-In test measurements. The IR-Camera can also be seen (2)

The tests proved that the selected heat source was very adequate for carrying out the measurements, achieving satisfactory results. The only problem was its big size, particularly when taking into consideration that the equipment has to be mounted on a maintenance platform normally used for the inspection of wind turbines (see picture below).

To this, it must be commented that REETEC has two types of platforms, to be used depending on the size of wind turbines.

The “small-platform” for maintenance actions to rotor blades of approx. up to 30 m long:

- Mounting of the platform: approximately 1 hour;
- Visual inspection of a rotor blade: approx. 1 hour (when no difficulties are encountered);

The “big-platform” for maintenance actions to rotor blades of more than 30 m long:

- Mounting of the platform: approximately 2 ½ hours;
- Visual inspection of a rotor blade: approx. 2 hours (when no difficulties are encountered);

Fig.: digital picture of a “small” platform used for maintenance of wind turbines by REETEC.

Fig. lateral view of a “small” platform, as it can be seen, the working area is narrow.

Although the “bigger” platform is designed to for working on bigger rotor blades, its working space is pretty much the same as in the “small” platform, and that is really limited (see the picture above).

Therefore, the heat-source to be used has to be according to the special limitations.

Taking this into consideration, the consortium decided to use two smaller heat sources instead off one big one, as previously foreseen.

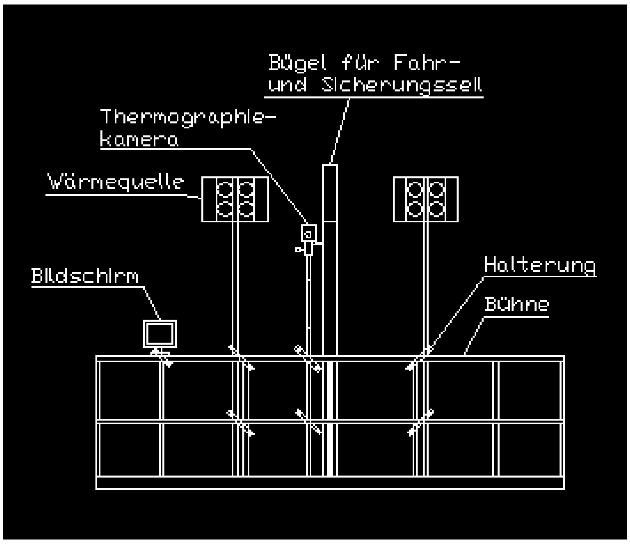
The selected heat source has 4 highly sophisticated studio halogen lamps with 650 W each, arranged in two groups, and completely installed in a steal framework for robustness.

Each of the two groups of lamps can be adjusted individually.

Fig.: digital image of the selected heat source with 2,6 kW of power

More information about the selected heat source can be found in the Annex D9: Selected / Adapted NDT Techniques and heat source(s) with documentation (Deliverable 09)

The equipment distribution in the maintenance platform would then look as in the graphic below:



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Task B4: Development of working methodology (including a recapitulation of the 2nd reporting period)

AmbiQual is responsible for developing all documentation related to PREWIND working methodology as well as for the Training method.

To achieve task objective, AmbiQual consulted project RTD partners, A.T, TTZ and CRIC and counted with experience of SMEs partners RETEC, Krypton, Alphatherm, ILIAKO, Jonica and EED.

Following, a short outline of work developed during last two years, that helped AmbiQual to develop the PREWIND working methodology;

- Task A1: defined critical parts of wind turbines considered for maintenance procedures, to be more efficient and guarantee a longer period of life equipment. Creating a tool with great value for the definition of a work methodology was demanded in task B4.

- Task A2: having collected information about existing European legal diplomas and standards; made it possible to develop a first draft of working procedures. For example: the NDT specifications for the inspections such as DIN EN 473 "Non-destructive - Qualification and certification of NDT personnel" (compulsory for all the operators and staff that work with Thermographic technology), as well as the norm DIN 54190-1 “Non-destructive testing - Thermographic testing - Part 1: General principles” as well as related to the choice of heat source.

- Tasks B1 and B3, had a great value for the definition of the PREWIND working methodology, the main source of information for better understanding NDT methods. AmbiQual took part in field tests and IR inspections of wind turbines.

All the collected information and deliverables developed was put together:

- IR Camera – A.T. and TTZ, IR experts, define the characteristics of IR Camera;

- Heat source – After testing several different heat sources, using cold and heat technologies, the decision was to use halogen lamps, thus they allowed great results when working with Lock-In analysis.

- Software – The TTZ in cooperation with REETEC and Krypton, developed a PREWIND maintenance software. This toll helps to manage a Database that plans and control maintenance routines of wind turbines, according to information stored and other inputs. For example; working hours of the units, possible defects in the past season and time of the year, etc. Software will be able to compile measurement reports in a format needed for certified working methods, and adapted to IRLookin V4.0, developed specifically for non-destructive testing with infrared cameras.

- Manuals – As result of previews work, partners developed also four important PREWIND manuals; IR Camera Manual, Operation and Assembly of working platform Manual, PREWIND Database V1 Quick Manual and the PREWIND active Thermography evaluation catalogue (in development).

AmbiQual performed also interviews and telephone conferences with the involved SMEs and RTDs partners for better understanding the PREWIND objectives. For example in February 2006, AmbiQual organized a meeting in Portugal with the participation of TTZ and CRIC.

During this meeting several different types of IR measurements where discussed, as well as a protocol on “how to proceed” and “critical points”. Base in the shared information, the procedures were refined and an important document was developed - “MOQ.011.R00 - PREWIND inspection checklist” elaboration.

As explained before, for the execution of this task a straight contribution from all project partners was necessary. All these activities contributed to define a set of documents all necessary for a precise PREWIND working methodology. During this phase, there was also an analyzing period, continuous contact with all the partners and a complete understanding of the system was absolutely necessary requirements for developing this working methodology. AmbiQual contacted also certification bodies, to better understand the way to build a PREWIND working methodology that can be later on certified.

So, the documentation related to a future certification of PREWIND by the end users was defined, based on norms of the International Organization for Standardization ISO 9000 (Quality Management System). The categories of obtained documents were the following:

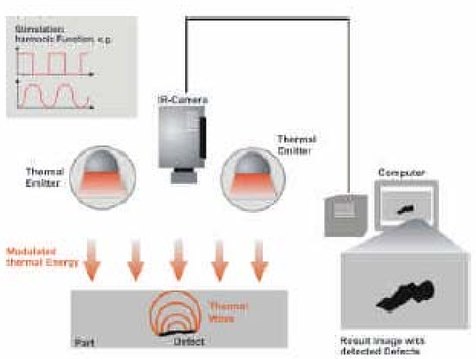
- Procedures;
- Instructions;
- Manuals;
- Models and
- Documents.

These documents are at this phase adequate to the reality of the work performed in the filed, by IR turbines inspectors.

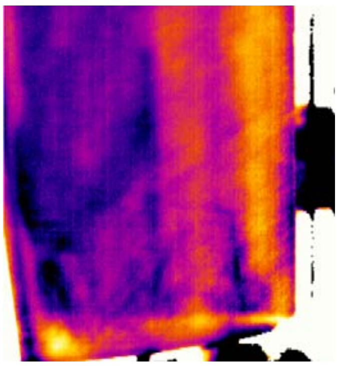
Referring to the point “*Procedures”*, four different procedures were identified for the working methodology; Active and Passive Thermography, related to specific characteristics of each measurement, Trainings needs and Control of documentation.

Following, a short description of two of the main working procedures: Passive and Active Thermography. These procedures state all the necessary steps to be followed to assure a correct IR inspection of a wind turbine.

PQ.001.R00 - Procedure for the thermographic inspection of wind turbines (Active Thermography): Applied to elements that do not produce generate “heat” during their normal operation, as for example, the rotor blades.



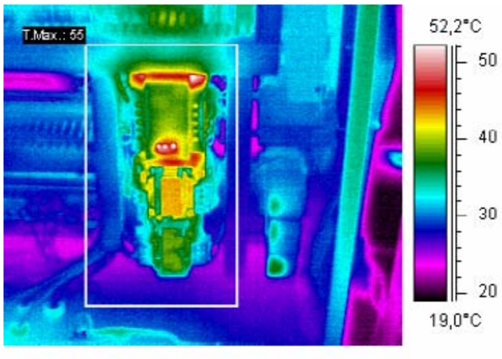
Active Thermography



IR Photo

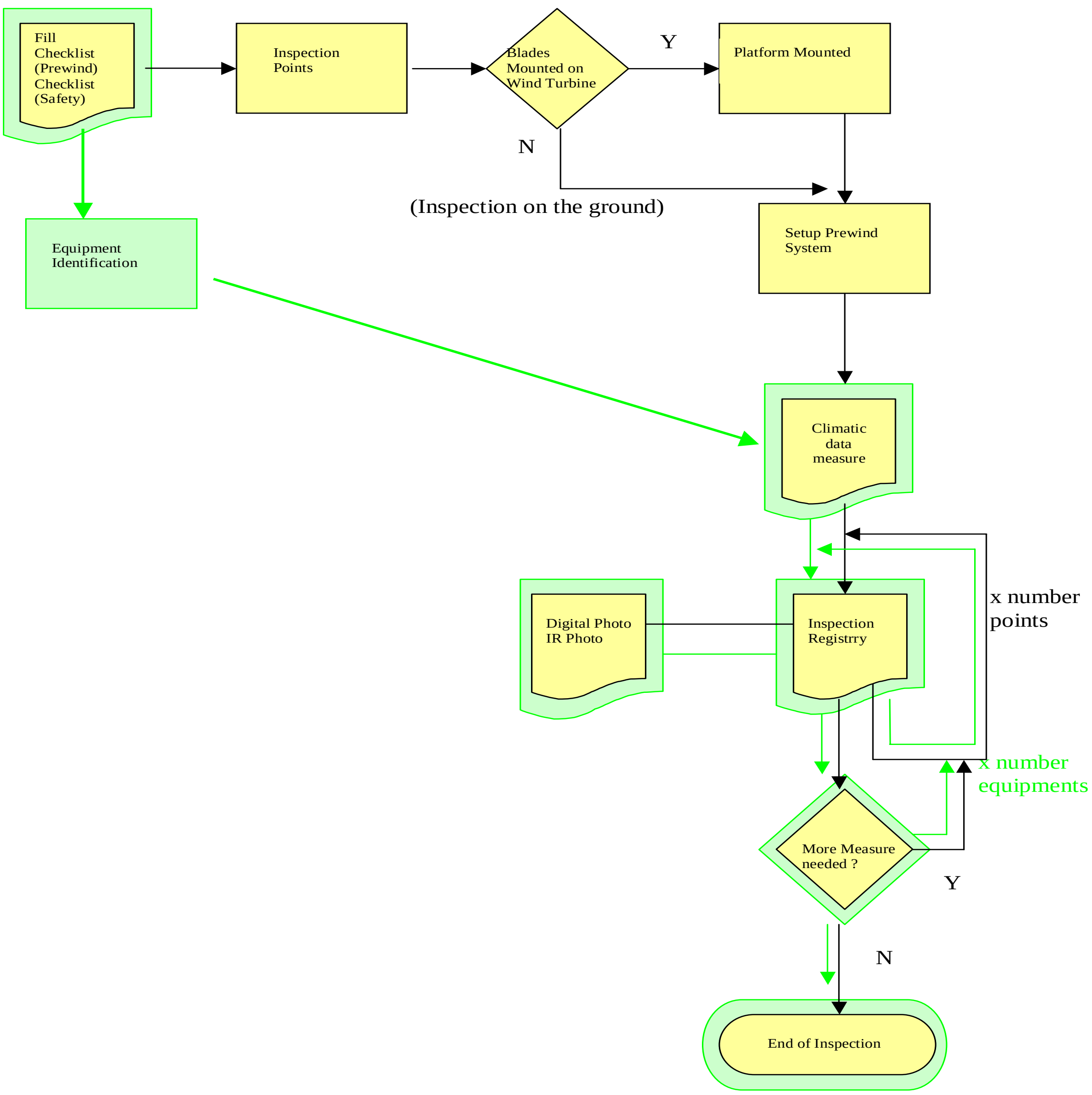
PQ.002.R00 - Procedure for the thermographic inspection of wind turbines (Passive Thermography).: For inspecting any component that produces heat during its operation, as for example an electrical motor, a bearing, a disk-brake, etc..

Digital Photo



IR Photo – Passive Thermography

For a better understanding of both procedures, please follow the Process flowchart “DQ.002.R00”:



AmbiQual defined also *Instructions* on how to proceed in the field during an IR inspection. All of them related to the operational part of the process; “How to measure…” and “How to analyze…” the IR results.

One of the most important elements of PREWIND is the IR camera and its associated software, therefore the necessity of having Operation Equipment Manual, which is in the *Manual* section. There, it is possible to find tree other manuals that reveal the functioning requirements of the Operation and Assembly of the Working Platform, PREWIND Database v1_0 QuickManual and PREWIND and Active Thermography Evaluation Catalogue.

AmbiQual identified twelve *Models* as necessary, based in the great contribution between project partners. All partners contributed to the execution of “vital” forms and reports for this system. These documents help to fulfilled in a fast and efficient way, all field values and data to later analyse. A good example is the “Checklist for thermographic verification of wind turbines” or the “Thermographic report of wind turbines”. All the documentation can be found as Annex D05 to this report.

There is also a section for *Documents*, for some general documents, such as “Inventory of Main Parts/Components of wind turbines “. Following a list of all developed PREWIND documents;

Document Nº	Document Description
PQ - PROCEDURES	
PQ.001.R00	thermographic inspection of wind turbines (Active)
PQ.002.R00	thermographic inspection of wind turbines (Passive)
PQ.003.R00	Identification of Thermographic Training Needs
PQ.004.R00	Elaboration and Control of Documentation
I - INSTRCTIONS	
IQ.001.R00	How to perform a thermographic inspection of wind turbines
IQ.002.R00	How to analyse and evaluate the results of the PREWIND inspection
M - MANUALS	
M.001.R00	IR camera manual
M.002.R00	Manual for Operation and Assembly of the Working Platform
M.003.R00	Prewind Database v1_0 Quick Manual
M.004.R00	PREWIND Active Thermography Evaluation Catalogue.
MODELS	
MOQ.001.R00	Safety Checklist
MOQ.002.R00	Checklist for thermographic verification of wind turbines
MOQ.003.R00	Thermographic report of wind turbines
MOQ.004.R00	Controlled Documents Distribution List
MOQ.005.R00	Internal Training Session Record
MOQ.006.R00	List of Calibration
MOQ.007.R00	List of Maintenance for thermography equipment
MOQ.009.R00	Audit Plan
MOQ.009.R00	Non-conformity/Client Claim Report
MOQ.010.R00	Claims and Suggestions Register
MOQ.011.R00	PREWIND Inspection Checklist

MOQ.012.R00	List of thermographs.
DOCUMENTS	
DQ.001.R00	What is thermography?
DQ.002.R00	Process Fluxogramme
DQ.003.R00	Inventory of Main Parts/components of wind turbines
DQ.004.R00	Thermographic Training Matrix
DQ.005.R00	Heat Source
DQ-O06.R00	Master list of document

NOTE: All these documents are drafts

The documents in the table above represent the PREWIND working methodology (Deliverable 10). In the task C3, all project partners will review and analyze the PREWIND working methodology so it can be optimised.

2.2.3. Deviation from the project work-programme, and corrective actions taken/suggested

During the reporting period, no significant deviations from the work plan occurred.

2.2.4. List of deliverables

Work package	Del. No.	Deliverable name	Delivery Date	Status	Man-Months planned	Man-Months used
B	D 07	Developed characterisation of the parts/components document	Month 12	**Completed**	7,50	5,08
	D 08	Developed/Adapted preventive maintenance control software	Month 12	**Completed**	18,50	12,11
	D 09	Selected/ Adapted NDT techniques and heat source(s) with documentation	Month 18	**Completed**	14,00	12,99
	D 10	Developed working methodology	Month 18	**Completed**	23,50	21.8

2.2.5. List of milestones

Work Package	Deliverable No.	Milestones title	Delivery date	Status
B	M02	Working methodology of PREWIND complete	18	**Completed**

Work-package C – Testing and Evaluation of the Working Methodology (recapitulation of the 3rd. period).

The following table shows the amount of personnel resources planned for this work-package per participant and the amount used (more detailed information can be found in the Annex 1.

Work Package C: Person Month Table per Partner																	
		IAGs						SMEs						RTDs			
	TOTALS	FGW	APPA	APREN	APER	IWEA	GEAL	Alphatherm	ILIAKO	Reetec	Krypton	EED	Jonica	TTZ	AT	AmbiQual	CRIC
Used	**37,44**	2,20	1,50	2,00	1,63	3,38	1,13	4,94	2,61	2,35	2,15	0,13	2,66	3,91	4,86	2,00	1,00
Planned	***37,00***	*2,00*	*1,50*	*1,50*	*1,50*	*2,00*	*2,00*	*5,25*	*1,25*	*1,25*	*0,75*	*3,25*	*3,25*	*3,00*	*5,50*	*2,00*	*1,00*

2.3.1. Work-package objectives and starting point of work at the beginning of the reporting period

The objective of this work package is to test the PREWIND Methodology in the field; both types of inspection: active and passive thermography. The results of these tests were analysed in the assessment of the field tests.

2.3.2. Progress towards objectives:

Task C1 – Field tests of the working methodology

The first aspect to be clarified in this task was the accessibility to wind turbines, in order to be able to carry out the field tests. This was assured by the partners Krypton and REETEC, who have access to the units.

Field tests - Active Thermography:

Regarding the active thermography, the consortium needed to have a working platform to mount the prototype on. As it has been commented already before, REETEC has two types of platforms, to be used depending on the size of wind turbines.

The “small-platform” for maintenance actions to rotor blades of approx. up to 30 m long:

- Mounting of the platform: approximately 1 hour;
- Visual inspection of a rotor blade: approx. 1 hour (when no difficulties are encountered);

The “big-platform” for maintenance actions to rotor blades of more than 30 m long:

- Mounting of the platform: approximately 2 ½ hours;
- Visual inspection of a rotor blade: approx. 2 hours (when no difficulties are encountered);

In order to save time and resources, it was decided together with Krypton and REETEC to use the smaller platform for the tests in PREWIND. The smaller platform is easier to handle, and so the planning for the field tests is easier.

It was thought to be appropriate to perform the first series of tests on only one type of unit, to be able to compare the obtained results with each other. REETEC has also “good” access to a 600 KW wind turbine with LM 19.1 rotor blades (19 meter long) located near the town of Uthlede (little town within Bremen and Bremerhaven, in Germany), so it was decided to use this unit as our test-object. The turbine is about 5 years old, which means that it should be possible to “see” abnormalities through the LockIn thermographic inspection.

Fig.: digital pictures of the 600kW wind turbine in Uthlede. The images are from May 13th, when a field test was carried out.

Fig.: two diesel generators provided the required power for the platform and the heat source

All the required supports and anchorages for the PREWIND system were developed, so that it could be fixed to the platform.

Fig.: the IR-camera and other components had to be fixed to the platform using the custom made supports

Fig.: the PREWIND system was checked before the platform left the floor.

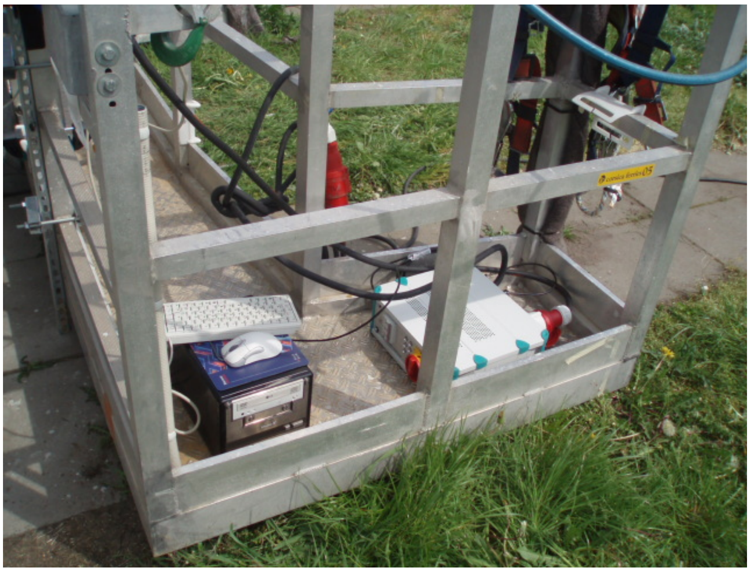


Fig.: the systems computer had to be provisorily put on the floor, it was necessary to be creative and improvise.

Fig.: the personnel of Reetec made sure that all the safety measures were taken.

Fig.: photo of the platform with the system leaving the ground.

Fig.: photo of the PREWIND system in action

Fig.: with the platform it is very easy to move up and down with the PREWIND system.

Once the system was mounted on the platform, and the platform had left the ground, it was very easy to move up and down.

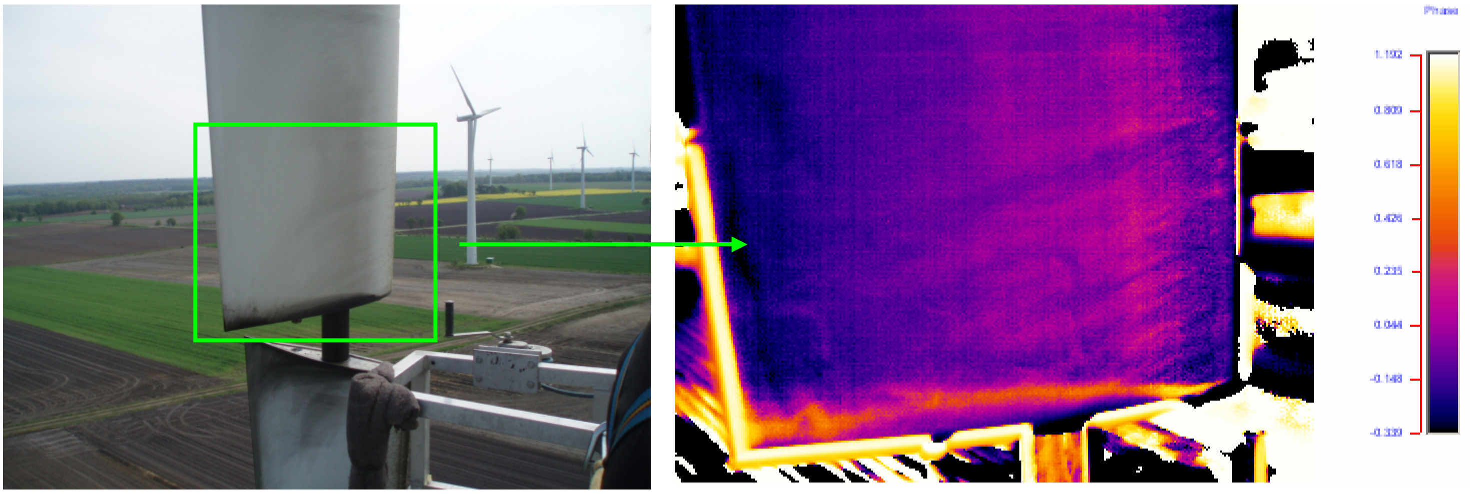


Fig.: digital and LockIn thermogramme done during the inspection of the rotor blade. The inner structure of the blade is clearly visible, showing that the hand—applied-resin had not been distributed evenly.

The inspection was carried out following the procedure for the active inspection of wind turbines (PQ.001.R00), as well as the other generated documents:

- PW-CHK01 (Inspection Checklist - Active)
- PW-IP01 (Thermographic Inspection Protocol - Active)
- PW-SREP01 (Inspection Report Template - Active)

Please see D20 (PREWIND Manual) to see these templates.

An example of a thermographic report of an active thermography inspection can be seen in the Annex D12.

After performing the first series of tests on rotor blades, it became quite clear that the system could successfully identify defects such as delaminations, air cavities, etc. The difficulty was to evaluate the seriousness of the irregularities detected in a simple way (the consortium had no experience in this matter when the field tests began). So it became obvious that an “evaluation catalogue” was to be compiled, containing as many examples as possible for all typical defects, so that the operator had references (“good” and “bad” examples), to determine in an easy way the status of the inspected section.

This simple but critical aspect had not been considered during the preparation of the proposal. For the consortium it was already clear that the system could provide good and precise results, however, it would be very important to gather as much experience as possible (as many examples as possible), to be able to provide an accurate evaluation.

So the consortium decided to prolong the field tests as much as possible (originally the field tests should last only 6 months, from month 19 to month 24) to gather as much testing material as only possible.

At this point it must be also commented that it is not always easy to have the opportunity to carry out tests. As it has been commented before, Krypton and Reetec assured the availability of wind turbines. However, the weather conditions play a very important role; normally it should not be to windy to be able to perform a successful inspection (if it is too windy the platform will swing, making the resulting images “moved” or unfocussed). And then, there is the fact that when the weather is good, normally the companies working on maintenance of wind turbines have to take advantage of it, so the platforms are busy and not available for tests.

At the end the consortium managed to perform around 150 IR measurements (this represents around 200.000 IR images). And so the “evaluation catalogue” could be compiled.

To this it must be commented that this catalogue is only the first draft, thus it needs to be fed continuously with new examples (please see also the Annex D12, for the first draft catalogue).

Field tests – Passive Thermography:

It was decided by the consortium to perform all the passive-thermography inspections in the same type of wind turbines, as was the case for the active thermography. This way, all the results can be compared to one another.

So it was decided to carry out the inspection on a turbine AN Bonus 1,3 MW / 62, which had been installed on 06/04/2000. The last maintenance action had been carried out on the 10/05/2006 (6 year maintenance), so it was not long ago.

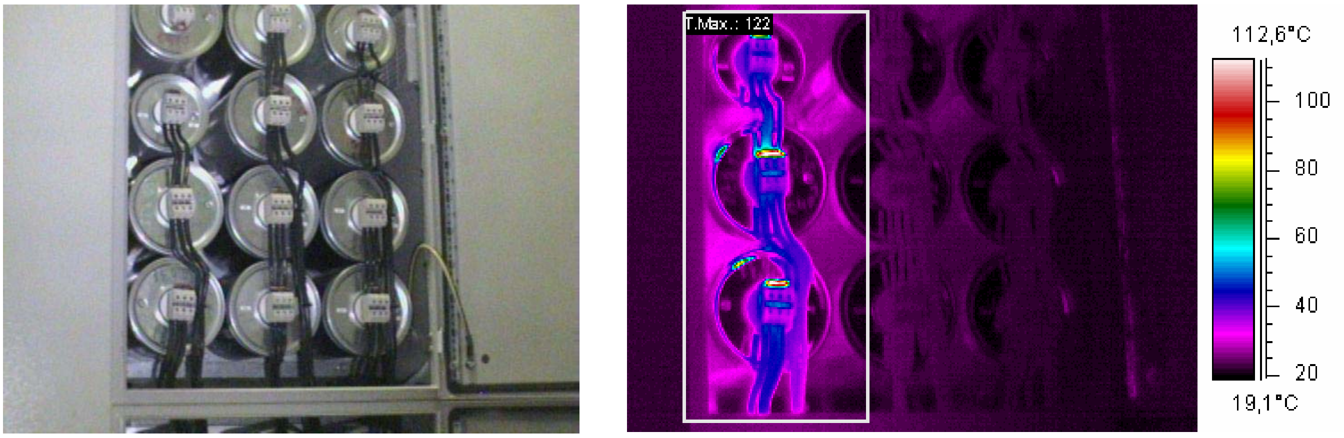


Fig.: Digital and IR pictures of the electrical cabinet A4 (the compensation cabinet). The thermogramme shows clearly which circuits are working and which not.

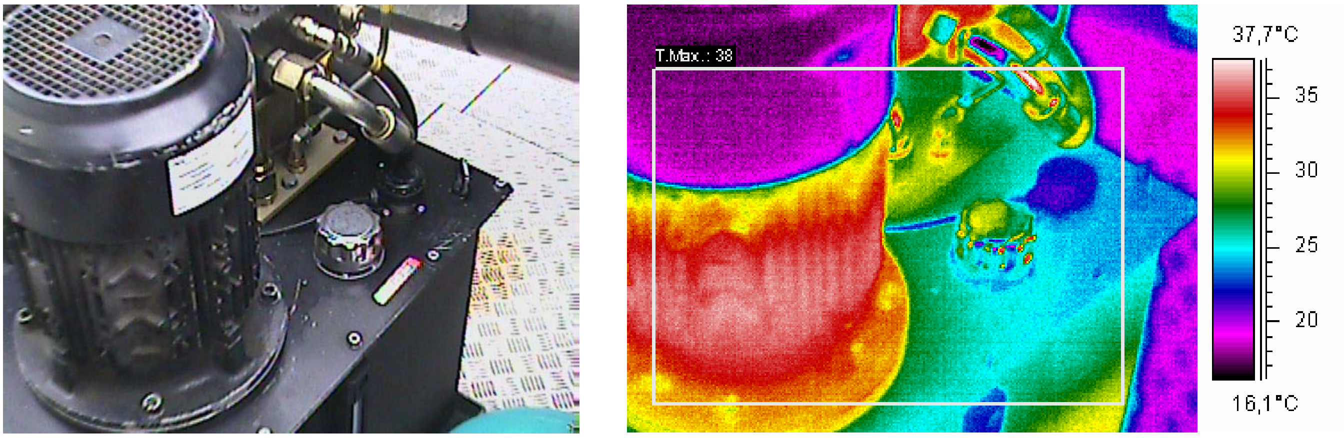


Fig.: Digital and IR pictures of the Hydraulic system of the wind turbine. The IR-image shows the level of fluid in the container.

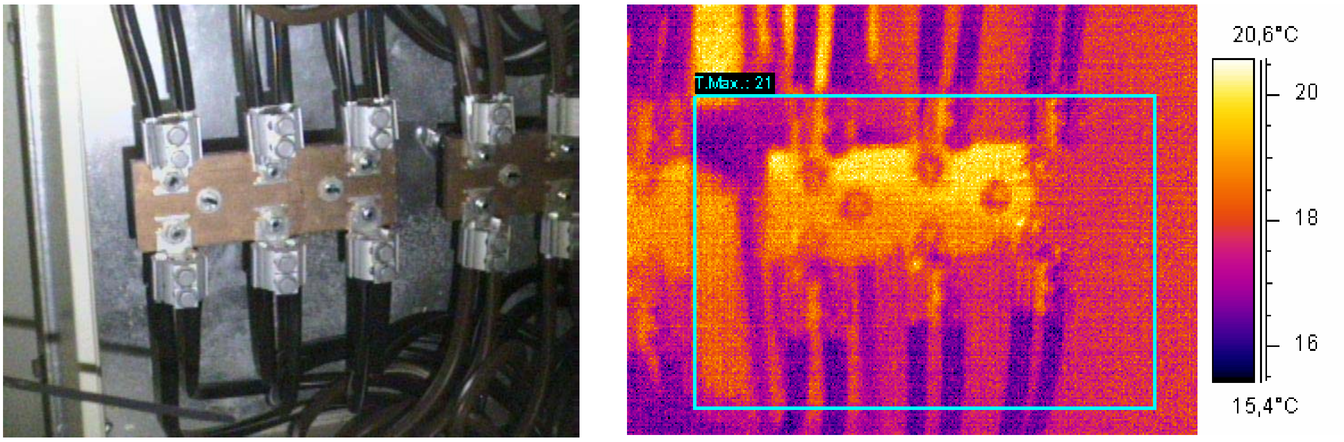


Fig.: Digital and IR pictures of a cable connection cabinet. If there was something wrong with one of the connections, the IR-Image would show a temperature difference within the different phases.

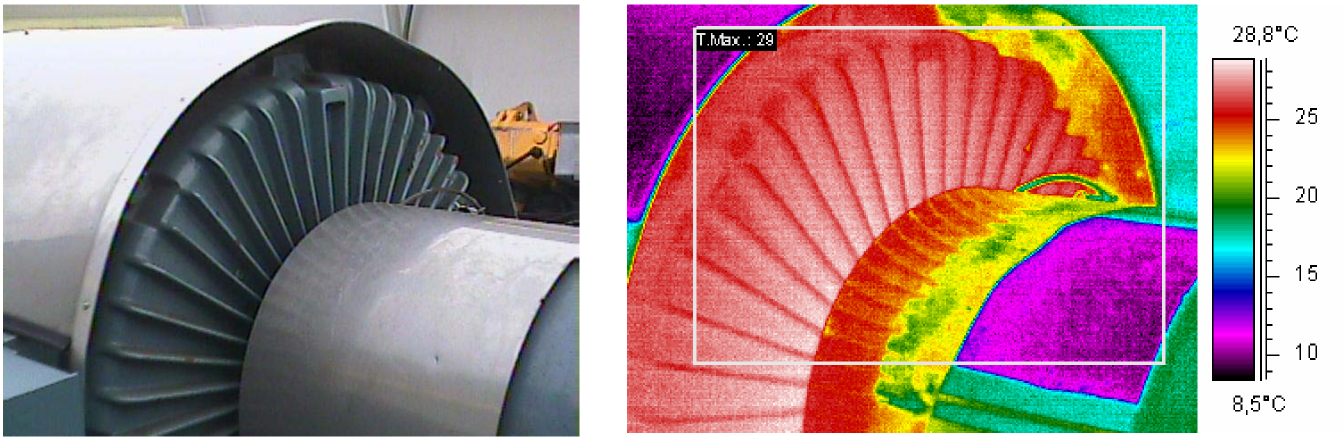


Fig.: Digital and IR pictures of the Gearbox / Generator Main Bearing - High Speed Shaft. If the main bearing was not in order, the friction would generate heat which would be detectable by the IR-camera.

The inspection was carried out following the procedure for the active inspection of wind turbines (PQ.001.R00), as well as the other generated documents:

- PW-CHK01 (Inspection Checklist - Active)
- PW-IP01 (Thermographic Inspection Protocol - Active)
- PW-SREP01 (Inspection Report Template - Active)

Please see Annex D20 (PREWIND Manual) to see these templates.

An example of a he thermographic report of an IR inspection (passive) can be found in the annex D12.

For the evaluation of the thermogrammes, there are many factors that have to be considered. Of course, when there is an obvious failure, the temperature differences will be so high within similar components, that the operator can conclude that a component is not working normally; for example a corroded electrical contact, a defect bearing, etc. will generate enough heat to be seen through the IR camera.

To determine weather a thermogram has a severity level 0 or 1 the subsequent criteria has to be followed: *Evaluation rules A, B and C*

Rule A: The inspected object has a temperature that according to the **NETA Severity Guideless** indicates the possibility of a deficiency – then the severity level will be assigned as Severity 1 (**see annexes of the Manual (D21): NETA Severity Guidelines**)

Rule B: The *normal temperature of operation*[4] of a component has increased (or decreased) more than 5 degrees Centigrade of its normal operation temperature range – then the severity level will be assigned as Severity 1

Rule C: IF neither A or B are “true” - then the severity level will be assigned as Severity 0

The normal temperature range of operation of a component is given by its higher and lower “normal” operation temperature. There are many factors that can influence the operation temperature of a component (ambient temperature, working conditions, etc.).

In PREWIND, the normal temperature range of operation of a component will be determined by averaging 10 temperature measurements of the mentioned component under similar conditions. The measured temperature values (during the IR-inspections) will be written in the template PW-SREP02.

For all the other cases that are not so obvious, unfortunately the temperature values measured cannot be generalized, and temperature ranges cannot be defined, that are applicable to all wind turbines of the same type to differentiate within components working normal and those that don’t.

The temperature values will vary depending of the location where the unit is installed (a turbine installed in Spain will have different, higher temperatures than a turbine installed in Sweden).

Another factor will be the time of the year when the inspection is carried out. In summer the temperatures will be higher than in winter.

And of course, the current wind speed will also have an influence on the thermal behaviour. The higher the wind speed, the faster that the components on the wind turbine will tend to rotate, therefore the higher friction will lead to higher temperatures.

[4] Normal temperature of operation of a component

Task C2 – Assessment of the working methodology

As it has been commented before, the testing phase for the project PREWIND demanded more resources than originally planned: time, man-power, etc. So, in order to achieve suitable results, the testing period was to be extended (Originally it had been planed to test from January 2006 to June 2006, but the consortium performed tests up to April 7007).

To this it must be commented that the Passive thermography did not present major problems. First, because the inspector does not require more equipment than the thermographic equipment (compared to the active thermography where a platform, a power source, heat source, computer, etc., are needed). And second, because the inspection is made to the equipments inside the wind turbine, the inspection can be performed at any time independently of the current weather conditions (of course: it must be windy, other wise there will be not “temperature” differences to be monitored).

Regarding the Active thermography, the situation was different. Although Reetec and Krypton always assured the accessibility to wind turbines, the possibility of being able to carry out an active thermography-inspection always depended from two main factors: the weather had to be suitable for performing such an inspection (not too windy, because then the platform will swing) and of course, a platform has to be available (during “high” season must of the platforms are in use).

First of all it must be stated, that this assessment is based on the expertise of the personnel involved in the field tests (to the best of their knowledge), and the experiences they made while performing the field tests.

During the project PREWIND around 150 IR measurements were performed (including both Passive and Active Thermography) containing around 200.000 images. All measurements were carried out following the procedures previously defined in task B4.

After having concluded with the field tests on wind turbines, the working methodology (measurement procedures) for both: Active and Passive thermography were found adequate, so it has been estimated, that no major modifications need to be carried out to them, but only some minor technical modifications (most of them on the active thermography) or suggestions.

<u>Passive Thermography</u>:

- The procedure for performing “passive thermographic inspections of wind turbines” (PQ.002.R00) was found adequate, so no modifications of corrections are though necessary.

<u>Active thermography:</u>

- The procedure for performing “active thermographic inspections of wind turbines” (PQ.001.R00) was also found adequate, so no modifications or corrections are though necessary.

Task C3 – Feed-back on the working methodology

<u>Passive Thermography</u>:

The only suggestion that the consortium could make to a user, is to start the inspection at the bottom of the wind turbine and to work his way up (normally, due to safety procedures, the wind turbine has to be turned off when personnel is inside the nacelle). This way, the inspector could go up inspecting all electrical panels (with the turbine still running), and if he has to shut off the unit when reaching the nacelle, he still will have better temperature contrasts for the inspection than if the turns the wind turbine off before starting to climb (of course, safety comes always first, so if there are clear regulations forbidding to climb to the nacelle with the wind turbine in operation, those rules need to be followed).

Besides that, the user will need to gather always sufficient information on the reference-temperature-values for the wind turbine he is inspecting, to assure its accuracy. The more measurements he performs, the better his results will be (inspections need to be repeated under as much weather conditions as possible to have a wide variety of reference values, thus the success of the PREWIND method depends on their accuracy).

Active thermography:

The only major comment to be made to the assessment of the "active thermography" inspections is that at the beginning of the field test it was determined that it was necessary to create an evaluation catalogue (the necessity for this document had not been originally foreseen at the preparation stage of PREWIND). A first draft for this catalogue was then created (and can be found in the CD, in the same folder as this document).

This document summarizes results of various IR Measurements on critical areas of rotor blades, and has comments to the conclusions obtained. The operator performing the inspection has then a reference, to which he can compare his results. With this tool he is able to judge the thermograms made in a more appropriate way.

The consortium is aware that the mentioned document will be more efficient, as more information is included in it. Therefore, a centralized management of the information generated will be organized after the project is concluded, so that all the partners using the PREWIND method can share and benefit from a joined source of information. This will be a dynamic catalogue that will always be growing.

During the field tests, it was concluded that other minor technical aspects had to be improved, such as:

- the brackets and clamps for fixing the PREWIND system to the platform need to be optimised;
- the way the platform is fixed to the tower needs to be improved, thus it swings very easily when light wind blows, or when the people on the platform move;
- the inspection computer should and its monitor should be fixed in a more appropriate way, so it does not interrupt the moving of the operators in the platform;

2.3.3. Deviation from the project work-programme, and corrective actions taken/suggested

The consortium experienced a considerable delay in the conclusion of this task. If it is true that the results obtained from the measurements were very promising from the early beginning (the consortium obtained IR images that showed defects clearly within the layers of laminate applying the active thermography); however, it resulted obvious that more measurements were required than originally planned. For this, the consortium had to redistribute the resources originally planned, and some partners resulted bringing a higher input of resources, while others had a minor participation.

The main goal was to achieve as much measurements as possible, to have as much references as possible. The consortium had to compile a reference catalogue which was not planed originally. It seemed however, that it was the only way to be able to obtain fast results during the evaluation of the IR images obtained (by comparing them to emails of the catalogue).

The consortium tried therefore to extend the field tests as much as only possible. To this it must be also commented that the platforms for performing the inspections were not always available and /

or the weather conditions did not allow to measure, factors that also contributing in delaying / prolonging the tests.

The consortium concludes however that it was the right decision, thus the results were very good.

2.3.4. List of deliverables

Work package	Del. No.	Deliverable name	Delivery Date	Status	Man-Months planned	Man-Months used
C	D 11	Developed and implemented field tests programme	Month 24	Completed	19.5	18.11
	D 12	Field test result document	Month 24	Completed	4.00	5.00
	D 13	Working methodology assessment document	Month 24	Completed	4.00	4.50
	D 14	Revised test programme and working methodology document	Month 24	Completed	9.50	9.83

2.3.5. List of milestones

With the fulfilment and achievement of the deliverables foreseen for the first work-package, it has been considered to have fully achieved the first milestone of the project.

Work Package	Deliverable No.	Milestones title	Delivery date	Status
C	M03	Working methodology field tested and evaluated	34	Completed

Work-package D – Development and Implementation of the Dissemination strategy

The following table shows the amount of personnel resources planned for this work-package per participant and the amount used (more detailed information can be found in the Annex 1.

Work Package D: Person Month Table per Partner																	
		IAGs						SMEs						RTDs			
	TOTALS	FGW	APPA	APREN	APER	IWEA	GEAL	Alphatherm	ILIAKO	Reetec	Krypton	EED	Jonica	TTZ	AT	AmbiQual	CRIC
Used	**90,28**	9,06	6,04	6,26	6,48	9,52	4,02	5,31	6,06	2,63	3,37	1,31	2,25	7,69	5,66	10,65	3,99
Planned	***79,50***	*9,25*	*7,00*	*6,50*	*7,00*	*8,00*	*8,00*	*3,25*	*1,00*	*1,00*	*1,00*	*1,00*	*1,00*	*8,25*	*4,00*	*10,25*	*3,00*

2.4.1. Work-package objectives and starting point of work at the beginning of the reporting period

The objective of this work-package is the development of a dissemination strategy for PREWIND. This work package will ensure the dissemination of the project results by implementing this strategy, conduction of workshops, etc. Technical and scientific steps for preparing the methodology for its certification of the working methodology after the conclusion of the project, will take place as part of the dissemination strategy. In addition marketing tools and a publicity strategy will be defined. This way the methodology will be available to a large number of SMEs.

2.4.2. Progress towards objectives

Task D2: Implementation of the dissemination strategy

Besides the dissemination of the PREWIND to their members, the IAGs where also committed to raising public awareness about the development of the project and the advantages of Infrared thermography as an effective technique for preventive maintenance of wind turbines (**Deliverable 17**).

For the successful completion of this task, a dissemination plan was defined in the document “Plan for Using and Disseminating the Knowledge” (Revised version from 20.11.2006; (**Deliverable 16**).

The following table summarises the main dissemination activities carried out by the PREWIND consortium to comply with the requirements of the document just mentioned:

Overview table:

Planned / actual dates	Type	Type of audience	Countries addressed	Size of audience	Partner responsible / involved
Several dates	Direct e-mailing (Circular letter)	AIGs members	Germany, Spain, Portugal, Italy and Ireland		FGW / IAGs
13 April 05	Hannover Messe	Industrial Partners, wind farm management	International	Interested SME companies	Automation Technology / Alphatherm
10 – 12 May 2005	Sensor & Test in Nürnberg	Industrial Partners, wind farm management	International	Interested SME companies	Automation Technology
20 – 24 September 2005	HUSUM WIND	Manufacturers, maintenance companies, Researchers	International		FGW / AT / TTZ / Alphatherm
Several	Project Brochure	Wind energy sector in General, related public authorities	International		TTZ / FGW / all partners
Several	Press release (press)	Public in General	Germany	Media (press & magazines)	FGW
08 – 10 November 2005	VISION 2005 in Stuttgart	Industrial Partners	International	Interested SME companies	Automation Technology
27.February – 02 March 2006	EWEA anual Congress (in Athen)	Wind energy branch, public in general	international		FGW
24–28 April 2006	Hannover Messe	Industrial Partners, wind farm management	International	Interested SME companies	Automation Technology

16 – 19 May 2006	Wind Energy – International Trade Fair - Hamburg	Manufacturers, maintenance companies, Researchers	International		FGW, TTZ, AT
September 2006	Article about PREWIND in the magazine NEUE ENERGIE (one of the most important magazines in Germany for renewable energies)	Wind energy branch, public in general	Germany	Wind energy branch, public in general	TTZ
28th to the 30th of September	Eolica Expo in Rome	Wind energy branch, public in general	Italy	Wind energy branch, public in general	APER
07 – 09 November 2006	VISION 2006 - Messe Stuttgart	Industrial Partners	International	Interested SME companies	Automation Technology
22 November 2006	Technical presentation of PREWIND at the DEWEK (most important international wind energy event in Germany)	Wind energy branch, public in general	International	Wind energy branch, public in general	TTZ, FGW
December 2006	Technical article about PREWIND in the magazine ERNEUBARE ENERGIEN (one of the most important magazines in Germany for renewable energies)	Wind energy branch, public in general	Germany	Wind energy branch, public in general	TTZ, Automation Technology
Several	Press release (press)	Public in General	Spain	Media (press & magazines)	APPA

11th and 12th of December 2006	Expert Meeting on the Application of Smart Structures for Large Wind Turbine Rotor Blades at the Delft University of Technology, Delft, the Netherlands	Wind energy branch experts	International	Wind energy branch experts	GEAL, IWEA
	Project website	General public	International		CRIC
Several	Links from partners websites	General public	All		The ones which has own web site
Several	Press release (press)	Public in General	Portugal	Media (press & magazines)	APREN / AmbiQual
Several	Press release (press)	Public in General	Ireland	Media (press & magazines)	IWEA / GEAL
2007	Project presentation	Public in General, wind farm management	Germany	Media, wind energy branch	FGW
February 28 - March 2, 2007	Energy and Environment International Fair, Madrid	Manufacturers, maintenance companies, Researchers	International		APPA / CRIC
19.04.2007	Presentation of Prewind on Hannover fair	Public in General	International		Automation Technology
May 2007	Presentation of PREWIND to the public at the EWEA event (EWEK) to take place in Milan, Italy	Wind energy branch, public in general	International	Wind energy branch, public in general	APER, FGW IWEA and PREWIND consortium

28.06.2007	Presentation of PREWIND at the Arbeitsgemeinschaft Windenergiedaten Schleswig-Holstein (AWD) (Working group Wind-energy-data for the region Schleswig-Holstein) in Rendsburg	Politicians, press and wind energy sector in General	Germany	150 people	FGW, TTZ

Other dissemination activities:

Other dissemination activities carried out include the updates to the PREWIND website (www.prewind.net), which is always online and provides all general information about the project (the web was updated in intervals ranging from 1 week from up to 6 months, depending on the project achievements to be updated).

Furthermore, a project's Poster (see Annex 3 of this document) was created and distributed among the project partners. The poster contains all relevant information about PREWIND and was presented at all fairs to which the members of the consortium attended.

A project brochure was prepared also (see Annex 3 of this document), which was also distributed by the project partners among their contacts, and during fairs and events where they are represented.

Several press releases and publications were made by the different partners involved in PREWIND in their countries of origin throughout the duration of the project (please see Annex 3 for an example)

A technical article about PREWIND was published also in the December (2006) issue of the magazine ERNEUBARE ENERGIEN ("Renewable energies"), one of the most important magazines in Germany for renewable energies, with about 45000 readers monthly (a scanned copy of this article can be found in annex D17). It must be mentioned that the article was strategically published just after the DEWEK, to support the information presented there.

Task D3: Dissemination of PREWIND to the members of the IAGs

All six participating associations (FGW, APPA, APREN, APER, IWEA and GEAL) included information about PREWIND in their normal correspondence to their members to inform them about the participation of the IAGs in the project. Updates about the advances achieved in the work plan where also distributed through mailings, brochures, etc. PREWIND was also included as a point in the agenda during general assemblies, etc. With these actions the IAGs fulfilled the necessary requirements for the successful completion of **Deliverable 19**.

Task D4: Preparation steps of PREWIND Methodology for quality certification:

AmbiQual with the support of the other partners prepared all documentation required to have the PREWIND methodology ready for its certification. Please in the annexes of the CD attached with this report to find the digital version of all required documents (Deliverable 20)

2.4.3. Deviation from the project work-programme, and corrective actions taken/suggested

No deviations towards the work-plan have occurred in this work package during the reporting period.

2.4.4. List of deliverables

Work package	Del. No.	Deliverable name	Delivery Date	Status	Man-Months planned	Man-Months used
D	D 15	Project presentation	Month 3	Completed	0.05	0.05
	D 16	Dissemination strategy and Plan for using and disseminating knowledge	Month 12	Completed	25.45	17.56
	D 17	Implementation of dissemination strategy for PREWIND complete	Month 36	Completed	10.75	35.31
	D 18	Developed PREWIND exploitation plan	Month 36	Completed	15.00	0.50
	D 19	Dissemination of PREWIND to the members of the IAGs complete	Month 36	Completed	17.75	22.64
	D 20	Technical and scientific steps for quality certification of the PREWIND Methodology	Month 36	Completed	10.50	14.22

2.4.5. List of milestones

Work Package	Deliverable No.	Milestones title	Delivery date	Status
D	M04	Dissemination strategy for PREWIND complete	12	Completed
	M05	Implementation of dissemination strategy complete	36	Completed
	M06	Steps for quality certification of the PREWIND Methodology complete	36	Completed

Work-package E – Development of a Training Method

The following table shows the amount of personnel resources planned for this work-package per participant and the amount used (more detailed information can be found in the Annex 1.

Work Package E: Person Month Table per Partner																	
		IAGs						SMEs						RTDs			
	TOTALS	FGW	APPA	APREN	APER	IWEA	GEAL	Alphatherm	ILIAKO	Reetec	Krypton	EED	Jonica	TTZ	AT	AmbiQual	CRIC
Used	**21,07**	3,04	2,50	1,50	1,00	1,25	0,56	1,16	0,00	0,00	0,00	0,26	0,00	1,51	2,43	2,25	3,62
Planned	***15,25***	*2,00*	*1,50*	*1,50*	*1,00*	*1,00*	*1,00*	*0,50*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*	*1,50*	*1,50*	*2,25*	*1,50*

2.5.1. Work-package objectives and starting point of work at the beginning of the reporting period

The objective of this work package is to develop a method for transmitting the know-how developed during the project to third parties (members of the IAGs, etc.), and to put that method into praxis.

2.5.2. Progress towards objectives

Task E1 – Development of a Training method for PREWIND

The training method for PREWIND has been summarised in a web-based tool including the manuals and the e-learning course. The e-learning course contains all the required information and guidelines to make a PREWIND inspection, it covers concepts about thermography, wind turbines thermography inspections and the PREWIND inspection protocols for active and passive thermography. The manuals contain the information of the different devices, software and processes used in PREWIND.

The web application consists on a Multilanguage password protected dynamical content web page. This means different things:

1.- The web page can be in different languages. IAGs members will be responsible of creating and maintaining their languages websites.

2.- 3 level users access have been developed.

a) *Super-user*. Consist on the web administration access, and is able to create any user, modify any language content, manuals, images, etc…

b) *Management user*. Consist on an IAG administration account, which can create users (IAGs staff) and modify language content of the web page.

c) PREWIND *user*. Has access unlimited access to the PREWIND web page.

3.- The web page content can be modified dynamically from a password protected web management tool. Only the Super-user and the management users have access to this webpage.

The e-learning tool is oriented to wind turbine inspection technicians. It has been structured in modules, that contain different chapters. Each chapter contains a didactic unit, with the necessary information about that topic. At the end of each chapter there are different questions that must be answered in order to evaluate the learning about the topic.

The different modules developed are:

1.- ***Thermography***. It contains all information about thermography, that it is necessary to make any thermographic inspection. It does not focus on wind turbines or any other specific device.

2.- ***Wind turbines thermography inspection***. In this module it is developed the thermography of the different components to be inspected with the Prewind method. It covers the different electrical and mechanical parts for passive thermography, and the rotor blades for active thermography.

3.- ***Prewind methodology***. This module covers the passive and active thermography Prewind processes

The manuals have been properly developed in order to cover all PREWIND issues. The following table shows all manuals developed.

Master List of Documents

Document Nº	Document Description
PQ.001.R00	thermographic inspection of wind turbines (Active)
PQ.002.R00	thermographic inspection of wind turbines (Passive)
PQ.003.R00	Identification of Thermographic Training Needs
PQ.004.R00	Elaboration and Control of Documentation
QPW-I01	How to fill the Checklist of PREWIND system assembling/verification
IQ.001.R00	How to perform a thermographic inspection of wind turbines
IQ.002.R00	How to analyse and evaluate the results of the PREWIND inspection
M.001.R00	IR camera manual
M.002.R00	Manual for Operation and Assembly of the Working Platform
M.003.R00	Prewind Database v1_0 QuickManual
M.004.R00	PREWIND Active Thermography Evaluation Catalogue.
MOQ.001.R00	Safety Checklist
-	Checklist of PREWIND system assembling/verification
MOQ.002.R00	Checklist for thermographic verification of wind turbines
MOQ.003.R00	Thermographic report of wind turbines
MOQ.004.R00	Controlled Documents Distribution List
MOQ.005.R00	Internal Training Session Record
MOQ.006.R00	List of Calibration

MOQ.007.R00	List of Maintenance for thermography equipment
MOQ.009.R00	Audit Plan
MOQ.009.R00	Non-conformity/Client Claim Report
MOQ.010.R00	Claims and Suggestions Register
MOQ.011.R00	PREWIND Inspection Checklist
MOQ.012.R00	List of thermographs.

DQ.001.R00	What is thermography?
DQ.002.R00	Process Fluxogramme
DQ.003.R00	Inventory of Main Parts/components of wind turbines
DQ.004.R00	Thermographic Training Matrix
DQ.005.R00	Heat Source
DQ-O06.R00	Master list of document

To see the final version of the training material, please check the CD attached.

Task E2 – Training of the Staff of the IAGs and core group of SMEs

Besides dissemination, the participating Associations (FGW, APPA, APREN, APER, IWEA and GEAL) were also committed to providing training on the PREWIND method to their members (**Deliverable 24**).

For this, the IAGs organized workshops (with the support of the RTDs) using the training material developed during the project.

The Training workshops had been originally scheduled to take place between the months of July – September 2006; however due to delays in the development of the training material from the side of the RTDs (the final version could only be finalized in May 2007), some IAGs decided to organize their training sessions only after having received the final version of the training manuals.

Some associations tried also to combine the workshops with a general assembly or a members meeting, to make it more likely for members with a though agenda to participate through a better utilization of the scarce resource: time.

These two facts led many IAGs to organize their workshops only towards the end of the project.

Workshops (D24):

FGW:

- Workshop: “PREWIND Training” in the German city of Heere (May 21th – 22th, 2007).

APPA

- PREWIND Workshop No.01: held in Madrid (Location: Hotel Wellington; September 13th, 2006);
- PREWIND Workshop No.02: held in Madrid (Location: Hotel Wellington; November 8th, 2006);
- PREWIND Workshop No.03: held in Madrid (Location: Hotel Wellington; March 14th, 2007).

APREN

- PREWIND Workshop No. 01: held in Lisbon on September 19th , 2006;
- PREWIND Workshop No. 02: held in Lisbon on February 14th , 2007;
- PREWIND Workshop No. 03: held in Lisbon on May 11th , 2007.

APER

- PREWIND Workshop: held in Milan on May 10th 2007 (this workshop was held during the EWEK where APER was represented, to take advantage of the assistance of people to that event)

IWEA

- PREWIND Workshop: held in Ennisdiamon on September 29th, 2006
- PREWIND Workshop: held in Dublin on March 31th, 2007

GEAL

- Workshop: PREWIND training held in Galway on June 7th, 2007 (for a practical part, GEAL even organized the renting of one thermographic equipment for this event).

2.5.3. Deviation from the project work-programme, and corrective actions taken/suggested

Although the first draft of the training material was delivered on time, the final version includes demonstration videos and therefore could only be delivered in May 2007. Therefore some IAGs decided to move their workshops towards the end of the project, to have the final version available (the other IAGs used the first draft material during their workshops).

2.5.4. List of deliverables

Work package	Del. No.	Deliverable name	Delivery Date	Status	Man-Months planned	Man-Months used
E	D 21	Training Module 1: Manuals for the application of the methodology	Month 24	Completed	4.25	4.66
	D 22	Training Module 2: Informative website	Month 24	Completed	4.25	4.66
	D 23	Training Module 3: e-learning information system.	Month 24	Completed	4.25	4.66
	D 24	Training courses to the staff of the IAGs and core group of SMEs.	Month 27	Completed	2.50	7.09

2.5.5. List of milestones

Work Package	Deliverable No.	Milestones title	Delivery date	Status
E	M07	Training modules complete.	24	Completed
	M08	Training courses complete	36	Completed

Only one deliverable is still incomplete, it will be however finished as scheduled in month 27.

Section 3 – Consortium Management

Work-package F – Project management

The following table shows the amount of personnel resources planned for this work-package, and the amount already used (more detailed information can be found in the Annex 1.

Work Package F: Person Month Table per Partner																	
		IAGs						SMEs						RTDs			
	TOTALS	FGW	APPA	APREN	APER	IWEA	GEAL	Alphatherm	ILIAKO	Reetec	Krypton	EED	Jonica	TTZ	AT	AmbiQual	CRIC
Used	**5,33**	0,00	0,00	0,00	0,00	0,00	0,00	0,56	0,00	0,00	0,00	0,00	0,00	4,07	0,70	0,00	0,00
Planned	***5,00***	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*	*0,50*	*0,00*	*0,00*	*0,00*	*0,00*	*0,00*	*4,00*	*0,50*	*0,00*	*0,00*

3.1. Consortium management tasks and information on coordination activities

Task F1 – Project Management

Administrative Management

During whole duration of the project, there were four official project meetings:

1. The Kick of Meeting was held in Galway, Ireland, and was hosted by GEAL (with the support of IWEA); 24th of September, 2004
2. the entire consortium met for the 1st year meeting held in Barcelona, Spain, on September 16th, 2005. Host of the meeting was the RTD partner CRIC.
3. The consortium met again for the 2nd year meeting held in Bremerhaven, Germany, on 29th – 30th of June, 2006. This time the host was the TTZ
4. The final meeting was held in Milan, Italy, at the offices of APER. The date of the meeting was June 22nd, 2007.

Please see the Annex 04 for the Minutes of the four official meetings.

Several “unofficial” meetings among the partners of the same country were organised in order to structure the development of the projects activities. Frequent meetings for example, among the German partners TTZ, Alphatherm and sometimes with the other RTD, Automation Technology, or with Reetec and Krypton, have taken place. The proximity of the location of these partners has facilitated the exchange of information, the facility of organizing short informal meetings to discuss about the project’s progress, etc.

The same phenomenon has occurred within the partners of other countries too, as for example: CRIC and APPA in Spain, or AmbiQual and APREN in Portugal, etc.

The communications between the coordinator and the partners did not show any difficulty, although the number of the partners in the consortium is high (16 partners of 7 different countries).

Many times during the reporting period, information about the work to be performed, work effort foreseen for each contractor involved and time schedule (deadlines) were supplied to all the consortium by means of emails by the coordinator who controlled the work and collected the works material needed for the foreseen deliverables.

All other information was distributed among the partners by means mechanisms such as email, fax, post or telephone.

As it has been commented before, the consortium managed to successfully exchange two partners (ISES for APER and TEGOPI for ILIAKO).

Scientific Management

Mr. Brinkmann, was the person responsible for the scientific management in the project. He took care that the tasks contained in the work-packages A - E, were carried out fulfilling the scientific goals of the project. He worked very closely, particularly with the partners Automation Technology and TTZ, a team that performed most of the IR-field trials.

Mr. Brinkmann communicated also with other partners, to assure the information flow and to allow all tasks to run smoothly. As it has already been stated before, Mr. Brinkmann has valuable experience in the field of IR-Thermography, and therefore played a key role in the inspections on wind turbines, and later on, supported the RTDs in the analysis of the results obtained.

Following a table showing the status of the deliverables for this work-package up to the moment of preparation of this report:

Work Package	Deliverable No.	Milestones title	Delivery date	Status
F	M09	Mid term review report complete	18	**Completed**
	M10	Final reports complete.	36	**Completed**

3.2. Project timetable and status

The consortium can inform that by the end of the 36 months of project all Deliverables and Milestones had been completed successfully. A few delays that took place during the development of the project where catched up, so that by the official end of the project no major delays were happening regarding the work-programme of the project, as scheduled in the Technical Annex of the contract with the European Commission (Contract No. COLL-CT-2004-500736).

Section 4 – Other issues

4.1. Overall contribution of the IAGs, SMEs and RTDs

In this section of the 3rd Periodic Activity Report the overall contribution of the IAGs, SMEs and RTDs performers is described. Following, the contribution, according to the division above mentioned is reported:

Industrial Associations/Groupings:

IAGs have collaborated with RTDs providing sector specific information to allow the scheduled development of the planned tasks. The IAGs have also provided the RTDs with some feedback regarding the applicability of the developed system in the market. The IAGs have also contributed tremendously to the dissemination of the project's results.

RTD performers:

The Research Institutes have carried out literature and internet research, as well as most of the technical work. The RTDs have also carried out some administrative tasks, engineering, planning, coordinating, testing, etc. Part of the activities carried out, have been the development of the working methodology for the system, the task that during this period has consumed the majority of resources.

SME core group:

SMEs collaborated by giving information about the processes and technologies, market situation on the wind energy branch, providing feedback based on their technical expertise and supporting the RTDs in the development of their tasks. Crucial has been the participation of the SMEs for enabling the access to wind turbines for the field tests. Without this support, this task would not have been possible.

They participated also on the project official meetings, as well as in bilateral meetings with different partners depending on their geographical location.

All Deliverables of the project are available to all Consortium partners, SMEs included. There is the possibility at all time, to get information about the work already carried out: general description of the sector, technology developed, results of the already developed tasks, etc.