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Influences of the Temperature Variations in the Gondola of the Goldwing S50/750 Wind Turbines

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***Abstract*— The use of wind energy is a decisive factor for human development, associated with the environment and capacity of people exploiting this vital resource. The investigation is part of predicting the behavior of the temperatures inside the nacelle of the Goldwind wind turbines S50 / 750 models installed in the Gibara Wind Farm. It supports its theories and analysis of computer-aided design (CAD), by monitoring the working temperatures, which interact with the forced ventilation system in the studied devices. The values analyzed result from continuous measurements carried out by the SCADA systems (Supervisory Control and Data Acquisition) of the studied machines. Which allows the diagnosis and early visualization of unforeseen incipient failures that currently occur under operating conditions standardized by the manufacturer. When the wind reaches speeds that exceed 11.5 m/s, major aggregates such as the gearbox and the generator fail. The results obtained in the investigation will allow to correct the program in the PLC (Logical Control Program) for the start-up and stop of the cooling system of the wind turbines in order to generate an ideal thermal balance for the working condition activities in Cuba, inside the nacelle, reducing the frequent occurrence of critical temperature values in the maximum limit that put the wind turbines out of service and therefore providing the wind farm with a higher coefficient of technical availability.**

***Keywords*—temperatures; goldwind wind turbines; wind farm; technical availability; monitoring; prediction; diagnosis.**

I. Introduction

Wind energy is a decisive factor for human development, associated with the environment and capacity of people exploiting this vital resource. We can see how they have not maintained continuous and constant development through time because of the possibilities that hydrocarbons once offered. But in recent years, due to the increase of fossil fuel cost and the environmental problems derived from their exploitation, there is a resurgence of renewable energies. Wind energy will play an essential role in the coming decades, marked by the depletion of fossil fuel sources. At a worldwide level, renewable energy will have an increasing impact [1].

That is why there have been multiple research lines and scenarios where scientists concentrate their efforts. Studying: "Lifetime considerations and fatigue loads control in wind turbines" [2]. Sensitive studies, such as maintenance optimization; wind loads on the blades, vibrations in bearings, all apply data monitoring through SCADA systems [3]-[8]. Thanks to the vertiginous development of computer science and mathematics, mathematical models have been developed and used to enhance the efficiency in the generation, maintenance, and design of wind turbines [9]-[14]. The results of many researchers converge that there are systems and aggregates with a high weight in the criticality of the functional states, so they have concentrated their research in studying and detecting failure modes in the gearboxes, generators, and SCADA systems. [15],[16].

The wind power generation industry's vertiginous development has allowed companies like GOLDWIND, GAMESA, SIEMENS, VESTA ENERCON, among others, to invest millionaire sums. These are based on state bonuses that encourage the development of standards, research and the installation of huge farms and wind turbines [17],[18].

In Cuba, wind generation began in March 1999 with the “start-up” of the T7-10 wind turbine in Cabo Cruz, in Granma's province with a nominal power of 10 kW. Although it was not a wind farm, it was the first and only wind machine built in Cuba with more than 1 kW of power and connected to the National Electro-Energetic System (SEN) [19]. Subsequently, other facilities were created such as Turiguanó Park, Los Canarreos and the experimental wind farm (WF) Gibara II in 2008. This was expanded with Goldwind technology creating what is known today as Gibara II, located in the municipality of Gibara, north of Holguin, comprising 6 wind turbines model S50/750 (60Hz) of 750 kW.

In the country, in December 2012, through a Presidential Decree number 3, they set up the creation of a government commission for the development of the policy for the perspective development of renewable energies and energy efficiency, in the period from 2014 to 2030. In June 2014, the Council of Ministers approved the prospective development of renewable energies policy in a period from 2014 to 2030 and its implementation schedule. The application will allow; among other things, to have 13 wind farms with a generation capacity of 633 MW [20]. These will be located in the Cuban north-eastern region because of favorable conditions for wind resources. Especially in Holguín where the installation of about 254 MW is boosted.

With this regard, during the last years; in the province of Holguín: several studies have been carried out to boost wind energy, historical databases have been created including technical and organizational actions aimed at favoring the process of diagnosis, maintenance, and operation in installed wind turbines. This task convened by the Ministry of Energy and Mines is led by the Gibara Wind Farm staff, with the participation of researchers from the Engineering and Project Company for Electricity (INEL), the Machinery Development Center (CEDEMA) in conjunction with researchers from the University of Holguin. Models were also developed to predict the heights wind behavior (50 - 100) m; and the wind effect on wind turbine blades.

Complementing investments in January 2011, the Wind Farm Gibara II started operations with a nominal power of 4.5 MW [21]. The installation guarantees part of the electrical energy consumed in the municipality of Gibara. However, the technically possible wind potential to be installed in the area, exceeds 120 MW. The coastal strip between Gibara and the neighboring city of Puerto Padre exceeds 350 MW with average speeds of 6.8 m/s [22]. Allowing approximately a 26% capacity factor in the studied technology, according to the Goldwind 50/750 Wind Turbine "power curve" [23], as shown in Fig. 1.

Through statistical processing of the failure databases that occurred in Gibara II wind farm, the maximum levels of generation are not reached in most cases. Due to the occurrence of failures and unplanned stops, all this makes the wind turbines technically unsuitable when the wind speed exceeds 11.5 m/s. For environmental operating conditions according to Cuban Standard 220-3:2009, in Annex B, where the values for the external project conditions are established [24].

Considering the above mentioned, along with the high levels of salinity, there are adverse conditions that undermine the operational reliability of electromechanical equipment in operation. This investigation aims to determine why and how the variations of temperatures influence the gondola of the Goldwind S50/750 wind turbines, installed in the Wind Farm Gibara II, in its technical availability.

m/s	kW
4	16
5	32
6	88
7	165
8	257
9	363
10	474
11	579
12	660
13	719
14	754
15	769
16	773
17	764
18	751
19	736
20	721
21	707
22	697
23	692
24	692
25	695

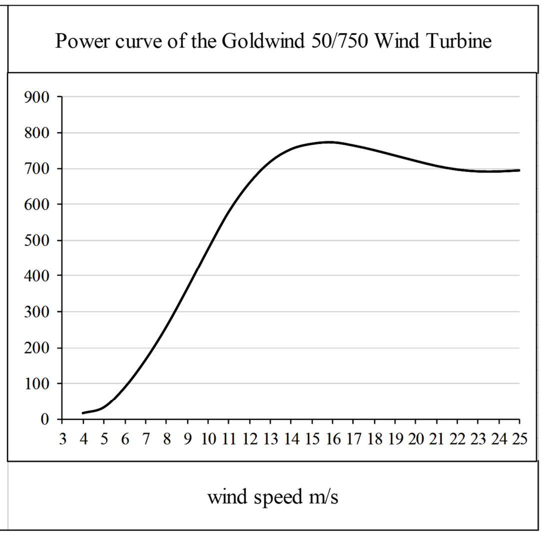

Fig. 1 Power curve of the Goldwind 50/750 Wind Turbines, generation (kW) in correspondence with the wind speed (m/s)

II. Materials and Methods

Worldwide, reverse engineering has become a powerful design and technical analysis tool, which has many benefits. One of them is allowing to carry out studies and calculations based on existing geometries. Using reverse engineering and the design program SolidWorks version 2018, CAD modeling of the wind turbine gondola is performed. The temperature behavior analysis inside the gondola is developed by means of a model studied with the use of Flow Simulation complement. The extensive benefits offer heat transfer analysis, fluid studies, establishing the boundary conditions, and utilizing previously built black boxes. The recommended time step size Δt for a transient thermal analysis is related to the length of the conduction element and the material's properties. The larger the thermal diffusivity, the smaller must be Δt and the length of the element.

$$\Delta t \le \delta^2 + 4\alpha \quad (1)$$

Where:

α = thermal diffusivity = K/ρc (the units are expressed in length/time)

δ = conduction length (in linear elements it represents the length of the element; in flat or volumetric elements, the diagonal of the inscribed circle or sphere)

K = conductivity
ρ = mass density
c = specific heat

In the simulation, the databases generated by the SCADA, analyzed in the investigation, show that the Electric Generator (EG) is the main source of heat generation inside the gondola. As can be seen in the correlation made to the more than 55 thousand temperature measurements that the study has. The wind speed exceeds 11.5 m/s and generator temperatures in the winding reach values between 970C and 1320C, being transferred to the other components through heat transfer mechanisms. Table 1 shows a sample of these measurements. The sample collected was taken in different months of the year and in the operation's six wind turbines.

TABLE I
TEN-MINUTE DATABASE IN THE GOLWIND WIND TURBINE INSTALLED IN THE WIND FARM GIBARA II, CUBA

Date/time	**Temperatu - re 3 (°C) Generator Winding**	**Tempera ture 5 (°C) gearbox Oil**	**Temperatu re 7 (°C) Gondola exterior**	**Wind speed (m/s)**
05/04/2017 13:50	102	63	25	11.5
24/03/2017 13:50	132	67	25	11.5
13/03/2017 16:50	119	66	25	11.5
13/03/2017 16:00	116	65	25	11.5
13/03/2017 14:40	114	65	25	11.5
13/03/2017 12:10	97	62	25	11.5

As known by many researchers, SCADA systems have enabled the development of 4.0 technology in the wind industry, for the advantages they provide in the creation of large databases, monitoring and control of parameters and variables. The combined use of databases and digital twins enhances simulation and convection analysis inside the gondola as main heat transfer mechanisms in simulations In the software used to develop the simulation (SolidWorks 2018), the convection mechanism is applied as the fluid layer adjacent to the hot surface becomes hotter. Its density decreases (at constant pressure, the density is inversely proportional to the temperature) and becomes floating. A colder (heavier), near-surface fluid replaces the one being heated, forming circulation patterns. Similar to the one shown in Fig. 2.

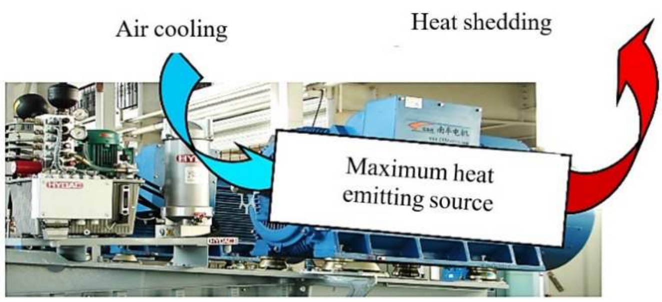

Fig. 2 Power generator for Goldwind 50/750 Wind Turbines

In SolidWorks version 2018 for heat transfer analysis, the heat exchange rate between a temperature fluid Tf and the face of an area solid at temperature Ts is governed by Newton's cooling law, which is expressed as follows:

$$Q_{convection} = h\,A\,(T_s - T_f) \quad (2)$$

Where h is the convection heat transfer coefficient, h is measured in $(W/m^2) * K$ or $(Btu/s * inch^2) * F$.

The convection heat transfer coefficient (h) depends on the fluid's movement, geometry, physical and thermodynamic properties.

Along with the studies of convection behavior inside the gondola, conduction transfer behavior is known, making it possible to predict temperatures of the bearing number one of the (EG), the main cause of the shutdowns activating alarm 526 in the Goldwind S50/750 wind turbine.

Heat transfer by conduction obeys the Fourier law, which states that the heat conduction rate Qconduction is proportional to the heat transfer area (A) and the temperature gradient (*dT/dx*), or:

$$Q_{conducction} = -K\,A\,(dT/dx) \quad (3)$$

Where K, the thermal conductivity, measures the capacity of a material to conduct heat. K is measured in W/m.ºC or (Btu/s)/inch.ºF.

The wind turbine under study is a horizontal-axis three-bladed machine with a unitary nominal power of 750 kW. With a Class II-a rotor diameter extended to 50 m, upwind rotor and active orientation, with fixed rotation speed and fixed blade pitch. Stall or loss of aerodynamic lift power regulation, through a transformer connected to the network, with a single-coil squirrel-cage asynchronous generator.

Since the park was set up for experimental purposes, it was arranged to investigate manuals, catalogs and plans of the technology under study. Which facilitated the construction of CAD models and CAE studies. The objective is to obtain models that allow controlling the temperature variations inside the gondola. Also, to positively influence the prolongation of the technical availability periods at wind turbines installed. It is recommended to satisfy the current need for diagnostic systems, that perform rapid detection and can also correctly distinguish or classify fault patterns [25].

In the specific case, the implementation of fault diagnosis systems is considered of great importance, not only by the researchers but also by the Gibara II Wind Farm operators. Where continuous failure occurrences related to unforeseen temperature variations, result in large economic losses due to associated states of operational unavailability. Diagnostic techniques allow to improve the efficiency of the process and the operability, maintainability, and reliability of these systems [26].

Since the end of the last century, maintenance researchers perceived that, system diagnostics have developed to a point where the available information is of such volume that man needs the help of the computer to get the most benefit [27]. Evaluation of wind farm operating conditions, requires knowing the status of generators and wind turbines. In order to do so, control, monitoring and data acquisition (SCADA) data are used [28]. The investigation provided a database that reflects 831 incidents of alarms that occurred in the six wind turbines studied during the last five years, 41.6% of which occur due to temperature-related alarms. “The monitoring of components through SCADA is crucial in the technical condition of wind turbines. By studying parameters such as temperature, the working conditions of the main aggregates can be known” [29].

III. RESULTS AND DISCUSSION

Statistical analysis of the control databases to technical parameters provided by the wind farm specialists under study. It can establish the relationship between technical alarms and alarms related to high temperatures in bearing number one of the generators, as shown in Fig. 3. Quantitatively translating, the databases include the incidents of the alarms that occurred in the six wind turbines studied in the years from 2014 to 2018.

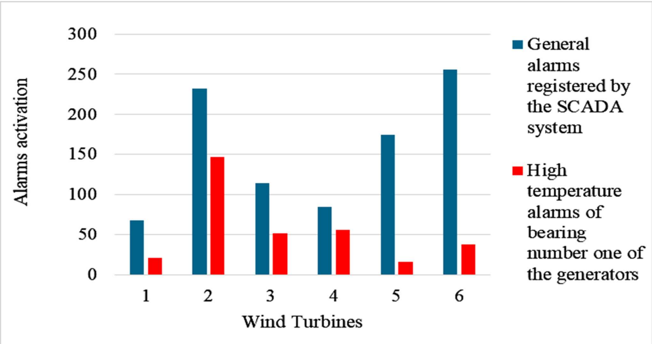

Fig. 3 Correlation study between alarms in the Wind Farm Gibara II and alarms due to high temperatures that caused failures between 2014 and 2018.

Validating the definition; when the wind reaches speeds that exceed 11.5 m/s, major aggregates such as the gearbox and the generator fail. Alarms and programmed actions that relate the failures in the cooling system, with the technical availability of the equipment, are automatically generated. The investigation by applying the failure tree technique establishes in Figs. 4 and 5, the relationship between the variables. Based on what is defined by the manufacturer in the Automatic manual [30].

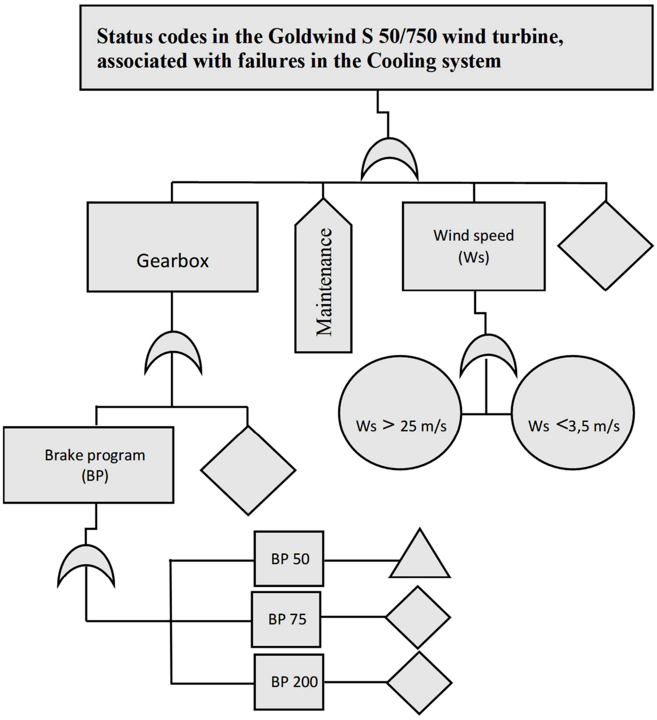

Fig. 4 Relationship between aggregate failures and brake programs in the Goldwind S50/750 Wind Turbines

Database like the one shown in Table 1, generated by the SCADA system corresponding to the first study period from March 12 to April 9, 2017, were standardized and processed, with samples exceeding 55 thousand measurements, where the determining variables of the work process under study were selected. Observing the requirements of “fan ignition inside the gondola set by the manufacturer to guarantee the oil temperature below 60°C, the gondola below 40°C and indoors below 65°C respectively” [30].

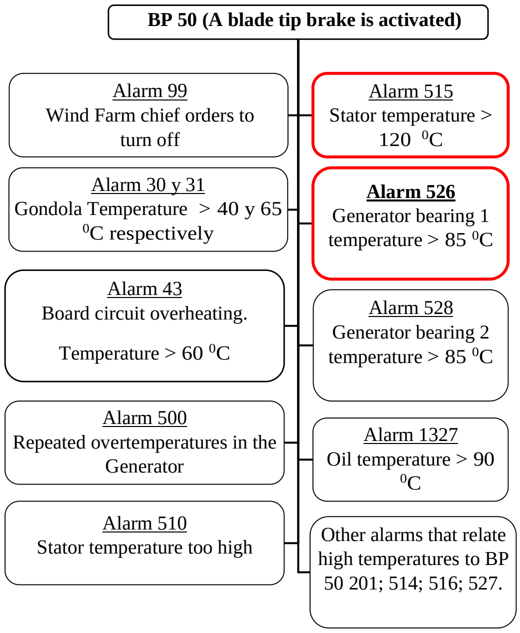

Fig. 5 Relationship between the brake program 50 and the alarms programmed in the PLCs that integrate the Goldwind S 50/750 Wind Turbines

This research establishes the relationship between wind speed and work transformation in mechanical energy applied to shaft and use to operate the generator, based on the manufacturers. In this process there are significant increases in temperature in some elements, which were monitored with PT 100 sensors responsible for measuring temperatures in the components studied inside the gondola. The installed PT 100 allows the acquisition of data by the control and automation system. The processing and response for the activation of the aggregates responsible for maintaining the desired temperature and functional values within the permissible range.

This validates the theory that temperature variations influence the inside of the gondola, and can generate overuse in the brake system and inefficiency in the generation. Causing premature failures in the physical structure of aggregates such as the cable of the brake system, the blades (primary brake system of the equipment) [23]. Caused by over-exploitation of systems.

Once the relationship between the temperature and operational availability has been analyzed. We proceeded to simulate the failure patterns of the cooling system of the equipment studied in the operating conditions of Cuba. Since this would allow to operate with technical and organizational solutions, minimizing:

- Estimated Costs of Unavailability associated with temperature states.
- Temperature failures according to status codes
- Time in hours required for reset according to status codes.
- Indirect costs associated to the sum of all failures.

The arguments presented clearly demonstrate the need to achieve temperature stability, inside the gondola, where the forced ventilation system plays a leading role in the thermal balance and heat transfer that occurs between the aggregates that make up the equipment under study. The cooling of the main turbine components is done by a mixed oil and air cooling system, that is mainly inside the gondola, linked by the automatic to the brake system.

The following Table shows a summary of the cooling system in the fundamental components that make up the wind turbine.

TABLE II
SUMMARY OF THE TYPES OF COOLING'S BY COMPONENTS TAKEN FROM THE MANUAL

No	Component	Type of cooling
1	Gondola	Forced ventilation
2	Center	Natural air
3	Gearbox	Oil
4	Generator	Air / forced ventilation
5	Hidraulic	Oil

The prevalence of cooling through forced ventilation in the fundamental components can be seen, which have different working temperatures as shown in Fig. 6.

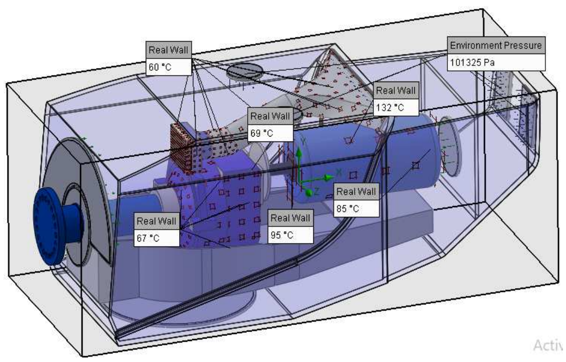

Fig. 6 Representation of real temperature conditions at different points registered in the gondola of a wind turbine studied in the WF Gibara II at wind speeds of 11.5 m/s

So it is necessary to know the behavior of the equipment in its total composition, which can be known with a study of the state of a mass of air based on mathematical functions, some of an experimental nature, which do not allow simple calculations, but it can be comfortably done by graphic methods based on the following [31]:

$$HEAT = HEAT_{SENSITIVE} - HEAT_{LATENT} \quad (4)$$

Sensitive heat: heat produced by the change in temperature of a substance. In the case of atmospheric air it is the heat added or extracted to the air without varying the relative humidity.

The previous expression is in accordance with the research problem. Because inside the gondola, thermal behaviour patterns are closely related to the wind speed. This is directly related to both the consumption and generation of electrical power during operation of components; such as: fan electric motors, oil pump and generator. Generating a heat release, just as it occurs in the gearbox, being directly proportional to the wind speed.

Considering that the electrical power consumed by an engine is used, almost all of it, to produce mechanical energy, the relationship between the two is given by its performance and the difference becomes sensible heat. Thus, we have:

$$W_m = W_e * \eta \qquad W_t = W_e * (1 - \eta) \quad (5)$$

Where:
W_e the electrical power consumed in W; W_t the thermal power dissipated in W;
W_m the mechanical power delivered in W; and Ŋ the efficiency for one unit [2].

In this case study, it would be to reverse the function and instead of determining We, it would be to calculate the mechanical power received in relation to the wind speed and to be able to determine the generated electrical power (Wg). This would allow to calculate the heat dissipated by the generator instantly. Offering the opportunity to the forced ventilation system, where the fan's electric motor will be linked to the SCADA and will work according to the temperature and wind speed values, optimal for tropical regions, such as the one being studied.

$$W_t = W_g * (1 - \eta) \quad (6)$$

Given the fact that, for any ventilation system to function properly, in addition to determining the flow, it is necessary to establish a current between the point (or points) of air intake and those of extraction to generate a "sweep" between the cold air inlet and heat generating focus.

Therefore, the necessary air flow in m³/h to maintain the maximum differential chosen between the indoor and outdoor temperature of an area to be ventilated (Q), can be calculated by the following equation:

$$Q = \frac{c(w)}{0.34} * (ti - te) \quad (7)$$

Where:

C: is the amount of heat ceded by the equipment to the environment, in W.

(ti - te) maximum permissible difference between the temperature of the indoor and outdoor air. A value of 5 is normally used for hotter environments and 10 in cooler areas.

Through a good ventilation system, a differential that ranges between 4 and 6 degrees above the outside temperature could be achieved [19]. Therefore, predictions and simulations of the working conditions to which the ventilation system could be subjected, validated by the heat transfer mechanisms, that support the calculation algorithms of the simulation program used for the study were developed.

The work was executed with the use of CAD software that allows simulating the behavior of simultaneous fluids with different temperature loads and wind speeds. The results obtained in the simulations shown in Fig. 7 have been validated using Delphi's method in collaboration of the expert committee. There was a concordance of over 85% among them, verified by Kendal's W coefficient with a value of 90%.

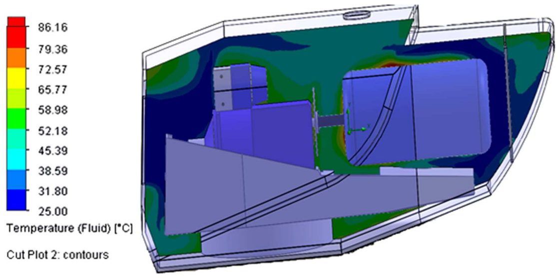

Fig. 7 Prediction of the ventilation system's working conditions in the Goldwind S 50/750 wind turbines installed in the Wind Farm Gibara II.

IV. Conclusions

When the wind reaches speeds that exceed 11.5 m/s, major aggregates such as the gearbox and the generator fail. Alarms and programmed actions to relate the failures in the cooling system with the technical availability of the equipment, are automatically generated. Fluctuations in the gondola's temperatures cause overexploitation of the equipment, when they reach the limits established in the unwanted condition states in their technical exploitation. The results obtained in the investigation disagree with what is established by the manufacturer. With the use of ICT tools, the forced ventilation system's working conditions can be determined preventively and automatically operated to achieve the desired heat transfer values and maintain the desired operational, technical availability.

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