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# A study on the specification of minimum design air temperature for ships and offshore structures

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ABSTRACT

Low temperatures can have a significant impact on the design and construction of marine and offshore structures as the performance and functions can be severely reduced. Compliance with relevant rules and regulations forms a prerequisite along with the specific design considerations to be taken into account. This paper provides an overview of the influence that the specification of the air temperature has on the materials selection used in design codes and standards. The paper focuses on the standards and the definitions used for the ambient air temperature and contributing parameters. To highlight the impact, analysis of air temperature data is presented for low temperature regions of the Russian Arctic, and observations from application to design standards for ships and offshore structures are provided based on this. From the analysis it is clear that the design temperature needs to be carefully selected to ensure the reliability of fracture toughness of structures.

## 1. Introduction

The performance of a ship or offshore structure are significantly impacted by the environmental conditions imposed by operating in a cold climate. The design of such structures consequently requires many additional considerations and assessments to be made to ensure it is commensurate with the performance expected. The impact of low temperatures on the reliability of hull integrity of ships and floating offshore structures should not be neglected as this has a significant impact on a wide range of aspects including the personnel safety and efficiency of operations.

The air temperature has a direct influence on the design and operations of ships and offshore structures. Low temperatures affect the structural properties for materials and results in the need for winterisation, such as the specification of heating and protection requirements for fire-fighting systems, fluids used in hydraulics, etc. Low temperatures influence also the installation and operation of equipment and systems. For example, freezing liquids within pipes, the humidity in the air in air intakes or materials becoming brittle are some of the effects, as illustrated by Bridges (2008) and Hauge (2012) for ships and offshore structures, respectively. The impact is also seen on personnel working outside in low air temperatures requiring short shifts with frequent pauses.

Designers commonly rely on industry standards to provide a level of reliability and safety, and this is also true for low temperature applications. There are many approaches for the definition of the design air temperature used in the marine industry, and the derivation of the design temperature is not always clear. It is also not clear how these definitions should be applied in the context of practical design and operation. This paper focuses on the requirements used for temperature in industry codes and standards for practical implementation. The paper focuses on the structural design aspects and steel structures in particular, and not those of winterisation of equipment, although many aspects are similar. The paper reviews the current standards and highlights the compatibility and discrepancies in design temperature definition. The variation in design temperature is illustrated by investigating the influence of the design temperature based on actual temperature data from Russian Arctic and the application to design standards for ships and offshore structures.

In particular the paper provides data analysis in relation to the determination of the design temperature that may be applied for floating offshore structures located in Russian Arctic and ships that may navigate

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along the Northern Sea Route (NSR). The temperature data is analysed according to different standards, such as the newly accepted criteria in the International Code for Ships Operating in Polar Waters (Polar Code, IMO, 2014a), the International Association of Classification Societies (IACS) Unified Requirement S6 (IACS, 2016a), IACS Polar Ship rules (IACS, 2016b), and the Arctic Offshore Standard ISO 19906 (2010a).

The aim of this paper is to highlight and discuss the contributing parameters associated with the specification of the design air temperature in industry standards for structural design with focus on the practical design aspects. In this paper direct quotes from standards are written in *italics* and referenced to the relevant section numbers. It should be noted that the standards are frequently updated. Thus the paragraphs that are discussed here may be changed somewhat, however the versions available at the present time of the study (June 2017) does not indicate significant changes to the principles discussed.

The paper firstly presents the different air temperature definitions used. Thereafter the paper is divided into two sections; the first providing analysis of air temperature data, and secondly investigating the impact of this on steel structures. In both sections some background and context is provided prior to presenting the results.

## 2. Design air temperature definitions

There are many different codes and standards for application in cold regions, giving various temperature definitions. These include, for example, the IACS UR S6 Unified Requirements for steel structures (IACS, 2016a), IMO Polar Code (IMO, 2014a), ISO 19906 standard for Arctic Offshore Structures (ISO, 2010a), and several steel grade requirements discussed in detail later. All these contain some kind of design temperature definition based on statistics of actual measured temperatures. Many of these regulations also contain requirements on how to measure the temperature; how often a reading is to be taken daily, as well as how high from ground the measurement is to be taken, etc. These details of measurements are not the focus of the paper and thus are not mentioned further.

Prior to any discussion or analysis on the design air temperatures, the following definitions on the temperature records are outlined, here reference is also made to Fig. 3. Assuming that a temperature record covering several years exists, the following definitions are used for different representative values from the temperature record:

- Mean Daily High Temperature, MDHT
- Mean Daily Average Temperature, MDAT
- Lowest Mean Daily Average Temperature, LMDAT
- Mean Daily Low Temperature, MDLT
- Lowest Mean Daily Low Temperature, LMDLT
- CedexAbsolute Maximum Temperature, ABS max
- Absolute Minimum Temperature, ABS min.

These definitions contain references to a 'mean' and an 'average'. It is important to consider the empirical basis for these averages (mean and average are used as synonyms here). Let us investigate daily temperatures and assume that the record covers $N$ years. These temperatures can be visualized to be indexed as $T_{ij}$ where index $i$ refers to $i$th day in year $j$ – and where subscripts min, max and mean are used for temperature values within one day (the $i$th day). Using this notation, MDLT, MDAT and MDHT are determined by taking the mean over the years for the day $i$. Thus these can be expressed as

$$MDLT_i = \underset{j=1,N}{Mean}\ T_{min_{ij}} \tag{1}$$

$$MDAT_i = \underset{j=1,N}{Mean}\ T_{mean_{ij}} \tag{2}$$

$$MDHT_i = \underset{j=1,N}{Mean}\ T_{max_{ij}} \tag{3}$$

Thus, LMDAT and LMDLT can be expressed as:

$$LMDAT = \underset{i}{Min}\ MDAT_i = \underset{i}{Min}\left(\underset{j=1,N}{Mean}\ T_{mean_{ij}}\right) \tag{4}$$

$$LMDLT = \underset{i}{Min}\ MDLT_i = \underset{i}{Min}\left(\underset{j=1,N}{Mean}\ T_{min_{ij}}\right) \tag{5}$$

The daily minima and maxima are defined as

$$ABS_{min_i} = \underset{j}{min}\ T_{min_{ij}} \tag{6}$$

$$ABS_{max_i} = \underset{j}{max}\ T_{max_{ij}} \tag{7}$$

The absolute minimum and maximum are derived by taking the minimum and maximum value:

$$ABS_{min} = \underset{i}{min}\ ABS_{min_i} = \underset{i}{Min}\left(\underset{j}{Min}\ Tmin_{ij}\right) \tag{8}$$

$$ABS_{max} = \underset{i}{max}\ ABS_{max_i} = \underset{i}{Max}\left(\underset{j}{Max}\ Tmax_{ij}\right) \tag{9}$$

Fig. 3 illustrates the data analysis for one weather station, in terms of the MDHT, MDAT, MDLT, $ABS_{max}$ and $ABS_{min}$ and presents values for each day of the year.

Based on the above, three main design temperature definitions can be described. These are:

- Polar Service Temperature
- Design Temperature, $T_D$
- Lowest Anticipated Service Temperature, LAST;

The definitions of these are given in Table 1.

Some background context to each of these definitions are analysed in detail in the next section, here one immediate comment is given. The first and third definitions are for 'service' temperature and second for 'design' temperature. The 'service' temperature refers to temperatures the ship or offshore structure can be operated in. In most approaches the 'design' temperature is lower than the 'service' temperatures – there might be added even a margin between Design Temperature and Operation (Service) Temperature (denoted in general $T_S$ below). This interpretation is not the one taken by some regulations.

## 3. Basis of design air temperature

As mentioned above, there is currently a range of different design air temperature definitions used in standards that account for the different design and operational characteristics of each application considered. There are many contributing factors that affecting the exposure in addition to the air temperature, including the water temperature, elevation above sea level, structural arrangement and insulation, etc. In this section we briefly discuss the different approaches.

The typical approach used in standards is based on the method of using an averaged temperature value for the design, and then allowing operations to a service temperature, which is often lower than the averaged value. The difference between these temperatures ranges from ten degrees, used in the IMO Polar Code, to twenty degrees as used in some ship classification rules, based on datasets such as IMO (2014b), and Kennedy and Patey (1997). This latter approach is also adopted not just in hull construction but also for application to equipment exposed to low air temperatures such as winterisation rules, and for example those for cranes (ISO, 2013), where the minimum