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INFLUENCE OF MEAN DAILY TEMPERATURE ON THE SELECTION OF THE CONSTRUCTION START DATE

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Internal and external influences determine the work output that can be achieved on any given day. One factor is external temperature, with a significant effect on the ability of workers to work outdoors. If temperatures are too hot or cold, losses of productivity occur and the labor consumption rate increases. This paper presents a survey indicating the percentage labor consumption rate increase to be factored in as a result of suboptimal external temperatures during reinforced concrete works. An example demonstrates how much the selection of the construction start date influences construction costs if the survey findings are taken into account. Both deterministic and probabilistic calculations were performed to address the uncertainties included in the equations and to illustrate the results in histograms and curves. For this purpose, Monte-Carlo simulations made it possible to assign distribution functions to individual input parameters to carry out the calculations. Potential savings were identified that result from choosing a favorable construction start date. In the event of any disruptions or delays, the potential effects on the labor consumption rate can be assessed systematically with respect to chances and risks.

Keywords: Loss of productivity, Monte-Carlo simulation, Non-linearity, Labor consumption rate, Probabilistic calculation, Histogram, Expert survey, Reinforced concrete works.

1 INTRODUCTION

Weather conditions influence the performance level of production factors. In the case of outdoor activities, prevailing external temperatures are one of the factors that determine the ability of workers to perform. At relatively low temperatures, workers at the construction site are no longer able to work at their “normal” productivity level because, for instance, their movement patterns are obstructed by warmer work wear (such as thicker gloves). Productivity is also reduced by breaks for warming up or re-positioning clothes. Furthermore, on-site heating equipment may create additional obstacles to the movement patterns of workers. When working at low temperatures, the accuracy and swiftness with which individual work steps are completed is reduced, leading to losses of productivity.

In the hot season, productivity is lowered, for instance, by additional breaks to relax and drink. Higher temperatures may also necessitate wearing of protective gloves when working with steel, for example, which may again slow down the movement patterns of workers. Personal protective equipment has a disruptive effect and makes workers feel even hotter.

The literature contains information on optimal daily temperature for various types of work. The details provided by Koehn and Brown (1985) make it possible to derive an optimal temperature range from 10°C to 21.1°C, irrespective of relative humidity. Thomas and Yiakoumis (1987) state an optimal range from 10°C to 15.6°C for labor productivity for relative humidities between 5% and 75%. Oglesby et al. (1989) define an optimal daily temperature range between 10°C and 21°C. Suboptimal daily temperatures influence the labor productivity of workers and have an effect on the required working hours [wh], for instance on the number of hours needed to produce one cubic meter of reinforced concrete. This ratio of working hours to units of quantity is referred to as the labor consumption rate [wh/m³].

Labor consumption rates and productivity are directly correlated to each other. Productivity is reduced if the labor consumption rate increases, and vice versa. The relative change in productivity ΔPL [%] can be determined using Eq. (1). For this purpose, the difference between "baseline productivity" and "actual productivity" is calculated and divided by baseline productivity. Baseline productivity follows from the reciprocal of the target labor consumption rate LCR_{TARGET} [wh/m³]. Actual productivity is derived from the reciprocal of the actual labor consumption rate LCR_{ACTUAL} [wh/m³] (Hofstadler 2014, p. 35).

$$\Delta PL = \left(\frac{\frac{1}{LCR_{TARGET}} - \frac{1}{LCR_{ACTUAL}}}{\frac{1}{LCR_{TARGET}}} \right) \cdot 100\% \qquad (1)$$

2 EXPERT SURVEY

In 2012/2013, a survey was conducted at Graz University of Technology among 35 Austrian and German respondents from construction trades and industry, who had an average professional experience of 17 years (minimum experience: 5 years; maximum experience: 43 years). One of the outcomes of this survey was the determination of the optimal daily temperature at 18°C, where workers enjoy ideal conditions to achieve their "normal productivity" level (robust mean estimator). Despite the fact that workers on European construction sites come from many different regions, the workforce employed in Germany and Austria predominantly comes from Central Europe; most of these workers are accustomed to continental climate conditions. There were no significant differences in the thermal comfort sensation of workers. Furthermore, a curve was determined for the increase in the labor consumption rate during reinforced concrete works, one that occurs if the daily temperature deviates from this optimal value.

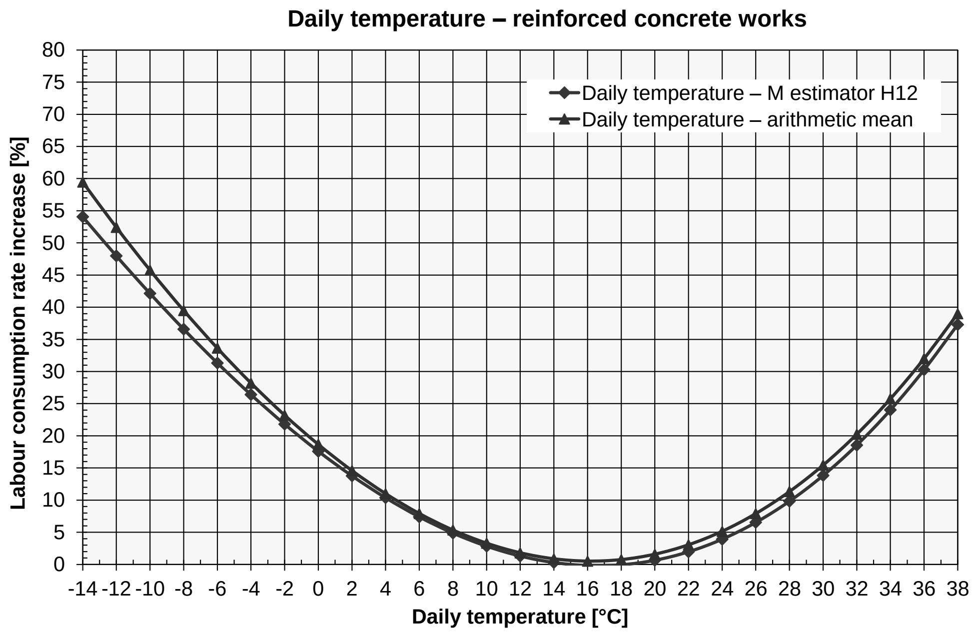

Figure 1. Diagram showing labor consumption rate increases depending on the calculation method – change in daily temperature – reinforced concrete works (Hofstadler 2014).

Labor consumption rates were calculated from mean values. They were determined using Eq. (2), inserting the temperature *TMP* [°C]. The results are valid for the ranges -14°C ≤ *TMP* ≤ 17.5°C and 18.5°C ≤ *TMP* ≤ 38°C.

$$\Delta LCR_{TMP,Mean} = 0.000319 \cdot TMP^3 + 0.058652 \cdot TMP^2 - 2.154455 \cdot TMP + 18.666935 \quad (2)$$

Robust mean estimators were determined (using Huber's M estimator method) to prevent biased outcomes and to avoid deletion of outliers indicated by respondents from the survey. For the purpose of determining mean values, this method included outliers and extremes only with a minor weighting. This approach is particularly suitable for a small amount of data. The labor consumption rate increase $\Delta LCR_{TMP,MS}$ [%] for the values determined using the M estimator method was calculated according to Eq. (3) by inserting the corresponding temperature *TMP* [°C] (Hofstadler 2014).

$$\Delta LCR_{TMP,MS} = 0.000466 \cdot TMP^3 + 0.048878 \cdot TMP^2 - 2.011685 \cdot TMP + 17.597270 \quad (3)$$

3 WORKED EXAMPLE

The following sections of this paper discuss a worked example that uses deterministic and probabilistic input parameters to consider losses of productivity, or labor consumption rate increases due to suboptimal mean daily temperatures.

3.1 Basic Considerations

This worked example relates to the Opera House project in Linz, Austria, and exclusively analyses reinforced concrete works. Assumptions of the overall labor consumption rate, mean wage cost and specified construction time were made by the authors (see Table 1).

Table 1. Calculation data – input parameters.

No.	Item	Deterministic value	Unit
1	Concrete volume	38,275.00	m³
2	Overall labor consumption rate	6.00	wh/m³
3	Construction time – reinforced concrete works	400.00	d
4	Mean wage cost	35.00	€/wh

The example investigates the influence of commencing construction in various months of the year on the basis of historical temperature data. Temperature data for the city of Linz (1971-2000 database) were provided by the Austrian *Zentralanstalt für Meteorologie und Geodynamik* (ZAMG; Central Agency for Meteorology and Geodynamics), and are publicly accessible online. Fig. 2 shows the mean daily temperature curve on a monthly basis, means of daily minimum and maximum values, and absolute minimum and maximum values.

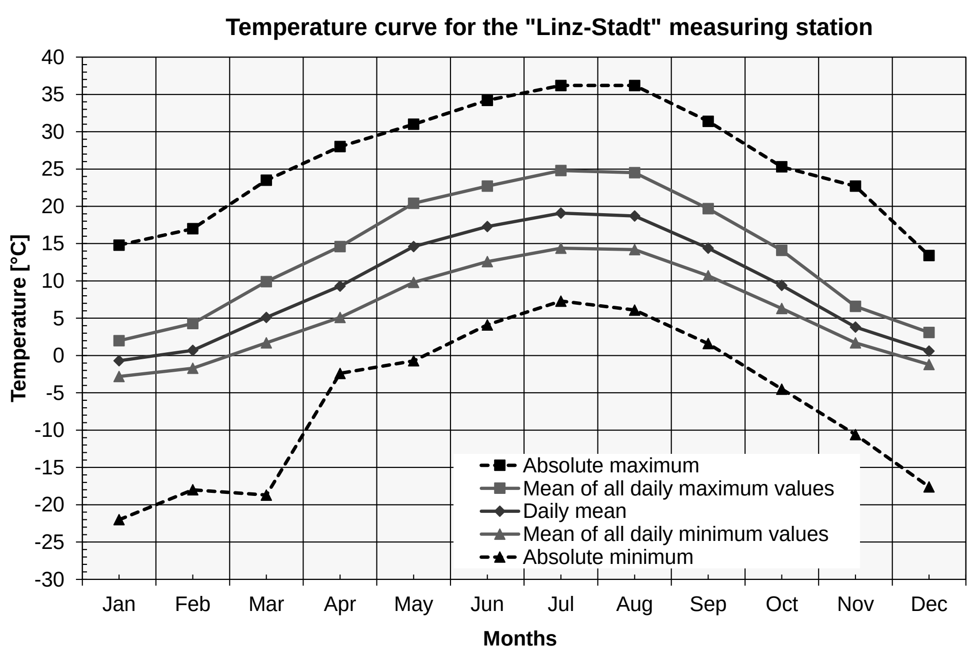

Figure 2. Temperature curve for the “Linz-Stadt” measuring station (Source: ZAMG).

The daily means recorded for each month are taken from the temperature curve for deterministic calculations. The probabilistic calculation relies on normal distributions of the temperature curve, where the daily mean of each month represents the mean value. The mean deviation between the daily mean and the means of all daily maximum and minimum values was considered to be a standard deviation for the sake of simplicity. Once all temperature measurement data has been recorded for a given period, this data can be applied directly to the calculations, or data-fitting operations are performed. If other input parameters (such as concrete volume or overall labor consumption rate) are associated with uncertainties, distributions can also be allocated to these parameters. This example used the corresponding deterministic parameters to simplify the procedure.

3.2 Calculations

This section includes an isolated consideration of the influence of daily temperature on total paid working hours and thus wage costs. Mean daily temperature directly influences the performance of workers. In the event of any under- or overrun of the optimal temperature, a loss of productivity occurs that, in turn, leads to a labor consumption rate increase.

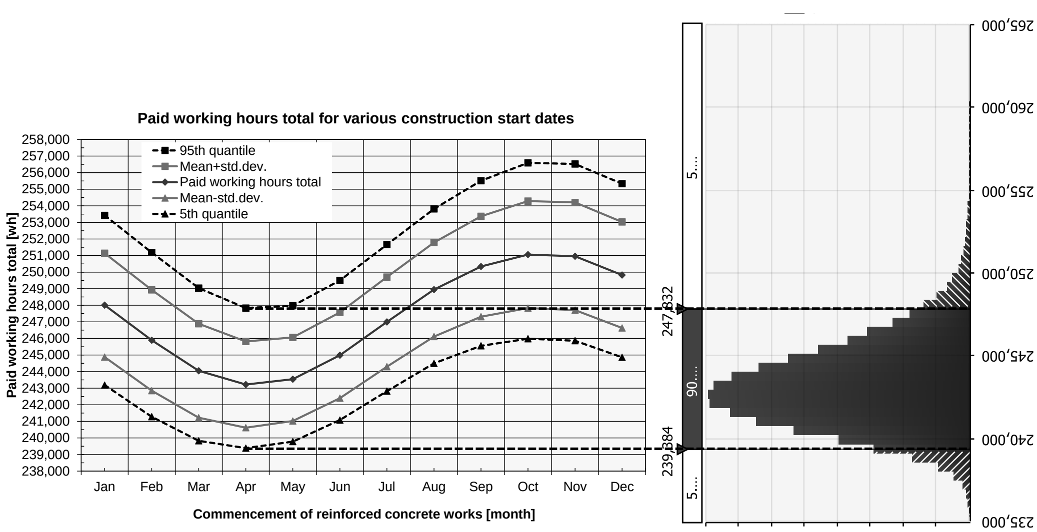

Figure 3. Paid working hour totals for various construction start dates – construction time 400 days.

By varying the construction start date and considering losses of productivity (Eq. (3)), a percentage labor consumption rate increase can be calculated for each month. Means were derived from the calculation results according to the proportional share of the months in which the work was performed, resulting in a mean labor consumption rate increase relative to the respective construction start date. A constant construction time of 400 days was assumed. Multiplying the concrete volume by the increased overall labor consumption rate gives the total number of paid working hours as a function of the construction start date. This made it possible to directly determine the

ideal month and date on which construction activities should start in order to carry out the work with the lowest number of paid working hours. Fig. 3 shows the result of the deterministic calculation as a graph (labelled "Paid working hours total").
In the probabilistic calculation, normal distributions were applied to the temperature for each month. Monte Carlo simulations made it possible to derive histograms for monthly totals of paid working hours. Fig. 3 shows curves of the simple standard deviation from the mean value, as well as of the 5th and 95th quantiles.

In our example, the lowest number of paid working hours was expected for a start date in April, whereas the highest was assumed for construction start in October. The difference of paid working hours relative to the mean values amounts to approx. 7.841 wh, which is equivalent to an amount of €274,435.00 at a mean wage cost of €35.00/wh.

4 CONCLUSIONS

The proposed method makes it possible to consider the influence of temperature on the performance of workers in relevant calculations. Any deviation from the optimal mean daily temperature will lead to losses of productivity or labor consumption rate increases. The influence of external temperatures on total paid working hours can be analysed by integrating historical temperature data while Monte Carlo simulations address uncertainties associated with the variables used in the equations. Histograms help to assess chances and risks with respect to estimated paid working hour totals and to create transparency with regard to the effects of shifting construction start dates, as well as to communicate these outcomes openly. Any need for measures to accelerate construction progress can be identified at an early stage, and decisions can be made on a more reliable basis with a view to existing chances and risks. Both clients and contractors can utilize the presented data analysis and derived labor consumption rate increase curves, combined with probabilistic computation methods, to assess any shift in the construction start date in terms of any associated additional working hours required for reinforced concrete works. Construction contractors, in particular, are thus able to assess any impact on on-site resource utilisation and to schedule corrective actions at an early stage in the process.

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