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INFLUENCE OF TEMPERATURE ON LABOR PRODUCTIVITY IN SHUTTERING WORKS

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In construction, total labor productivity is determined by the quality of effectively combining elementary production factors. For labor-intensive activities, one of the most important elementary factors is the people that the achievable labor productivity depends on. In respect of the circumstances under which they perform work, there are optimal weather conditions that meet the requirements for being capable of achieving normal output. To record the influence of temperature on labor consumption rates and labor productivity in formwork-related activities, an expert survey was conducted in Austria and Germany, which included a total of 35 respondents from construction contractors (from both construction trades and industry; survey period: August 2012 to April 2013). The average professional experience of respondents equaled 17 years (minimum experience: five years; maximum experience: 43 years). Filled-in questionnaires were analyzed using an exploratory data analysis. This paper outlines the statistical bases for Huber's M-estimator method, which was successfully applied in this analysis. Box plots of the variables were used to graphically represent distributions. A box plot describes the position and spread of a distribution, and provides information with respect to any outliers or extremes. Initially, the optimal daily temperature for achieving the highest possible labor productivity was determined. Subsequent work steps involved the documentation of changes in labor productivity that occurs if temperatures deviate from their optimal range.

Keywords: Loss of productivity, Labor consumption rate, Expert survey, M estimator method.

1 INTRODUCTION

Prevailing weather conditions are one of the key factors that influence outdoor work. Temperature is a parameter that plays a crucial role for output and labor productivity. At relatively low temperatures, the movement patterns of people are obstructed by warmer work wear, and they also require breaks for warming up. The accuracy and swiftness of movements is reduced. At high temperatures, additional breaks to relax and drink are necessary. Personal protective equipment has a disruptive effect, and protective gloves must be worn when working with steel. If a specific temperature limit is over- or underrun, workers are no longer able to achieve their 'normal' productivity level, which results in losses of productivity. There is no conclusive evidence, however, regarding the exact temperature that determines this limit.

Pertinent literature contains information on optimal daily temperatures for various types of work, including Koehn/Brown (1985), Thomas/Yiakoumis (1987), and

Oglesby *et al.* (1989). The details provided by Koehn/Brown (1985) make it possible to derive an optimal temperature range from 10°C to 21.1°C, irrespective of relative humidity. Thomas/Yiakoumis (1987) state an optimal daily temperature 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.

Daily temperatures that lie outside the optimal range adversely affect the output of workers, and thus their labor productivity. Any loss of productivity will lead to an increase in the labor consumption rate, and vice versa. The labor consumption rate describes the ratio of working hours expended to units of quantity produced [wh/m²]. Section 4 of this paper demonstrates the correlation between the labor consumption rate increase ΔLCR [%] and loss of productivity ΔPL [%].

2 EXPERT SURVEY

How can sound data be gathered that permit conclusions as to the optimal daily temperature whilst providing a generally applicable (as opposed to project-specific) quantitative description of the correlation between temperature and productivity? Any *ex-post* analysis will prove difficult because the type and circumstances of some of the work performed will have changed dramatically, and additional work will have been commissioned, compared to the original contract. The originally agreed-upon construction project is no longer identical to the project actually completed. It is almost impossible to correctly differentiate between individual losses of productivity according to their causes: changes in daily temperature and/or in the type of work, the circumstances under which work is performed, or additional work performed.

Further analyses thus relied on an *ex-ante* consideration as a feasible alternative. To generate sound data, an expert survey was conducted at Graz University of Technology to identify the quantitative correlation between daily temperature and labor consumption rate, and thus productivity. For this purpose, a total of 35 experts from construction contractors were asked to participate in this survey (from both construction trades and industry; survey period: August 2012 to April 2013). These experts had an average professional experience of 17 years (minimum experience: 5 years; maximum experience: 43 years).

Prior to analyzing survey data more thoroughly, an exploratory analysis was carried out to get an overview of gathered data. This work step was necessary to check data plausibility and distributions, as well as to identify any outliers. As part of this analysis, box plots of the variables were established to graphically represent distributions. A box plot describes the location and spread of a distribution and identifies any existing outliers. Outliers and extremes may strongly distort arithmetic means depending on their distance from the box plot 'antenna'. This outcome was prevented by applying the M estimator method, which succeeded in shifting existing outliers and extremes closer to the 'main set' of data by lower weighting. Diagrams and curves of labor consumption rate increases and losses of productivity were based on both arithmetic means and M estimators.

3 DETERMINATION OF OPTIMAL DAILY TEMPERATURE FOR CONSTRUCTION WORKS

Optimal daily temperatures are stated in degrees Celsius and apply to humidity levels normally recorded in Austria and Germany.

3.1 Description of Collected Data

All 35 respondents to the survey stated an optimal daily temperature value. Table 1 provides a summarized descriptive list of relevant parameters. The arithmetic mean derived from the answers amounts to 17.51°C with a standard error of 0.46°C, which is indicative of an accurate optimal daily temperature estimate.

Table 1. Descriptive list of parameters pertaining to optimal daily temperature.

Optimal daily temperature [°C]	
N	35
Mean	17.51
Standard error of mean	0.46
Standard deviation	2.72
Coefficient of variation	15.55%
Median	18.00
Mean absolute deviation	2.00
Robust coefficient of variation	11.11%
Mode	18.00
Minimum	12.00
Maximum	22.00
Spread	10.00
Skewness	-0.46
M-estimator (H16)	17.61
Standard deviation (H16)	2.79
Robust coefficient of variation	15.82%
Normal distribution (Shapiro-Wilk)	Nein

The median, i.e. the value at which 50% of the answers are above and below this threshold, equals 18°C and is thus similar to the mean. The coefficient of variation of 15.55% also indicates a far-reaching consensus among respondents. The stated minimum value amounted to 12°C whereas the maximum was 22°C. Skewness is negative in this case (-0.46), which is indicative of a left-skewed distribution and means that most stated temperatures were part of the upper range. A normal data distribution could not be confirmed (Shapiro-Wilk, $p < 0.05$). The histogram (Fig. 1) shows a graphical representation of this distribution. This histogram proves a clear deviation from the normal distribution, which is marked by the solid line.

A temperature of 18°C was stated most frequently (by 13 experts); these are represented by the highest bar. The modal average amounts to 18°C (see Table 1 with statistical parameters) and is thus identical to the rounded-up M estimator (17.61°C).

The survey thus provided a clear outcome of an optimal daily temperature of 18°C relevant to construction practice.

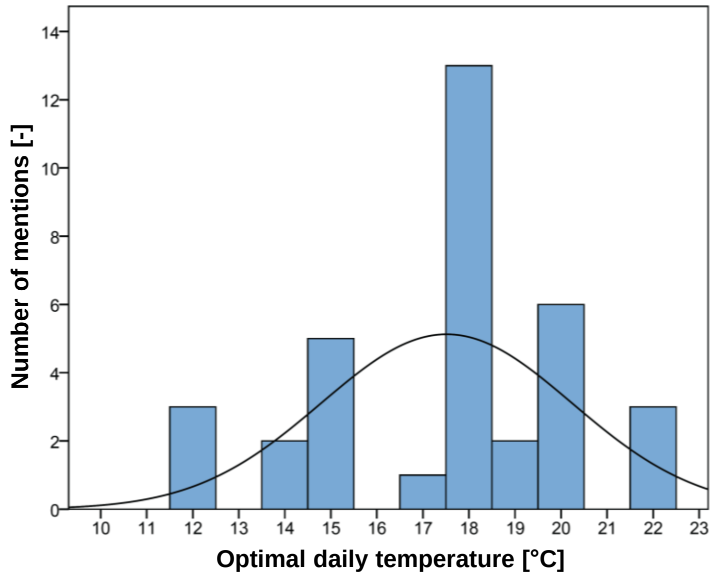

Figure 1. Optimal daily temperature histogram.

4 CHANGES IN DAILY TEMPERATURE – EFFECTS ON PRODUCTIVITY

The following sections discuss the influence of daily temperature on labor consumption rates and productivity.

4.1 Influence on Labor Consumption Rate

In the survey, experts were asked to state any changes in the labor consumption rate that would occur in the event of a change in daily temperature. The diagram in Fig. 2 shows the arithmetic means of the expert survey as a trend curve (curve labelled "Daily temperature – arithmetic mean"). The optimal daily temperature is reached at 18°C, associated with a labor consumption rate increase of 0%. The y axis indicates the labor consumption rate increase as a percentage whereas daily temperature values are shown on the x axis. Huber's M estimator method was applied to prevent distortion of the result by existing outliers and extremes. More specifically, the H12 M estimator was considered most useful for the purpose of this analysis. The associated trend curve that represents the labor consumption rate increase is labelled "Daily temperature – H12 M estimator" in the diagram. These two curves do not differ significantly from each other for daily temperatures from 2°C to about 20°C. When comparing the left and right branch of the curve, it becomes evident that lower temperatures are associated with a greater difference between the two curves. In the area left of the 18°C value, the difference amounts to about 1.2 percentage points at 0°C and increases to about 5.7 percentage points at -14°C. In the area right of the 18°C value, the difference between the curves amounts to about 0.9 percentage points at 22°C and 1.36 percentage points at 38°C.

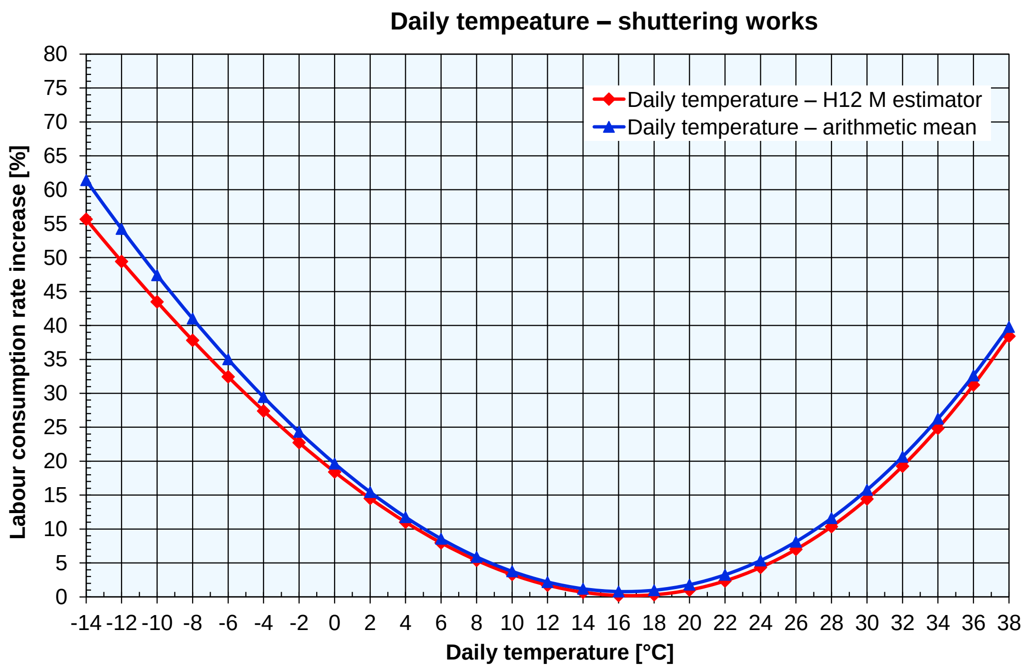

Figure 2. Diagram showing labor consumption rate increases depending on the calculation method – change in daily temperature – shuttering works.

The curve determined according to the M estimator method is thus recommended to indicate the trend in the loss of productivity because the related values show a lesser degree of distortion. The diagram and the equations shown below can be applied to the individual project phases. The labor consumption rate derived from mean values is determined using Eq. (1) by inserting the temperature *TMP* [°C]; it applies to the ranges of -14°C ≤ *TMP* ≤ 17.5°C and 18.5°C ≤ *TMP* ≤ 38°C. The optimal range for performing construction works lies between 17.5°C and 18.5°C.

$$\Delta LCR_{TMP,Mean} = 0.000338 \cdot TMP^3 + 0.059424 \cdot TMP^2 - 2.216378 \cdot TMP + 19.647675 \quad (1)$$

Robust mean estimators (Huber's M estimator method) were identified to prevent the deletion of outliers from the experts' responses for the purpose of the analysis and to eliminate the risk of distorted results. This method does consider outliers and extremes for the purpose of determining mean values, but assigns only a low weighting to them. It is particularly suitable for a small amount of data. The labor consumption rate increase $\Delta LCR_{TMP,MS}$ [%] for the values determined according to the M estimator method is calculated using Eq. (2) by inserting the corresponding temperature *TMP* [°C] (Hofstadler 2014).

$$\Delta LCR_{TMP,MS} = 0.000480 \cdot TMP^3 + 0.049747 \cdot TMP^2 - 2.057089 \cdot TMP + 18.415724 \qquad (2)$$

4.1 Influence on Productivity

The influence on productivity (loss of productivity ΔPL_{TMP} [%]) can be determined by inserting the labor consumption rate increase ΔLCR_{TMP} [%] in Eq. (3).

$$\Delta PL_{TMP} = \left(\frac{\Delta LCR_{TMP}}{100\% + \Delta LCR_{TMP}} \right) * 100\% \qquad (3)$$

The reduction in productivity ΔPL_{TMP} [%] as a result of the relevant daily temperature is calculated using Eq. (4) by inserting the temperature *TMP* [°C]; it applies to the ranges of $-14°C \leq TMP \leq 17.5°C$ and $18.5°C \leq TMP \leq 38°C$.

$$\Delta PL_{TMP} = -0.000022 * TMP^4 + 0.001654 * TMP^3 + 0.018082 * TMP^2 - 1.547056 * TMP + 15.308082 \qquad (4)$$

5 SUMMARY

Expert survey outcomes made it possible to determine an optimal daily temperature of 18°C. At this daily temperature, ideal conditions exist for workers to achieve their 'normal' productivity level. The curves and equations shown above can be used to determine the effects of suboptimal daily temperatures on the labor consumption rate or labor productivity of shuttering works. For practical purposes, it is recommended to rely on the curves determined according to the M estimator method (robust mean estimators) because these eliminate distortion by outliers and extremes.

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