Implementing Innovative Ideas in Structural Engineering and Project Management
Edited by Saha, S., Zhang, Y., Yazdani, S., and Singh, A.

ISBN: 978-0-9960437-1-7

INFLUENCE OF TEMPERATURE ON LABOR PRODUCTIVITY IN MASONRY WORKS

CHRISTIAN HOFSTADLER

Institute of Construction Management and Economics, Graz University of Technology, Graz, Austria

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 masonry works, 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

Outdoor work is essentially influenced by the prevailing weather conditions. Temperature is a parameter that is of crucial significance for output and labor productivity. At relatively low temperatures, workers' movement patterns are obstructed by warmer work wear, and they also require breaks for warming up. Furthermore, the accuracy and swiftness of movements is compromised. At high temperatures, people need additional breaks to relax and drink. Personal protective equipment has a disruptive effect, and protective gloves must be worn when working with steel. Workers are no longer able to achieve their 'normal' productivity level if a specific temperature limit is over- or underrun, which results in losses of productivity. There is no conclusive evidence; however, regarding the exact temperature that determines this limit.

Relevant 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) provide the basis to define an optimal temperature range from 10°C to 21.1°C, irrespective of relative humidity. Thomas/Yiakoumis (1987) indicate an optimal daily temperature ranging from 10°C to 15.6°C for labor productivity if relative humidity is between 5% and 75%. Oglesby *et al.* (1989) define an optimal daily temperature range between 10°C and 21°C.

Daily temperatures outside the optimal range have an adverse effect on the output of workers, and thus on their labor productivity. Any loss of productivity will lead to a labor consumption rate increase; the same principle applies vice versa. The labor consumption rate describes the ratio of working hours to units produced [wh/m²]. The correlation between the labor consumption rate increase ΔLCR [%] and loss of productivity ΔPL [%] is demonstrated in Section 4 of this paper.

2 EXPERT SURVEY

The question arises how sound data can be gathered that permit conclusions with respect 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 be difficult to establish 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 no longer corresponds 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.

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

Prior to a more comprehensive analysis of survey data, an exploratory analysis was conducted to get an overview of gathered data. This step was necessary to check data plausibility and distributions, as well as to identify any outliers. In this analysis, box plots were created for the variables in order to graphically represent distributions. A box plot describes the location and spread of a distribution and identifies existing outliers. Outliers and extremes may significantly distort arithmetic means depending on their distance from the box plot 'antenna'. The M estimator method was applied to prevent this outcome: by assigning a lower weighting, existing outliers and extremes were successfully moved closer to the 'main set' of data. 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 relate to humidity levels commonly recorded in Austria and Germany. Temperatures are stated in degrees Celsius.

3.1 Description of Collected Data

All 35 experts stated an optimal daily temperature. Table 1 provides a summarized descriptive list of relevant parameters. The arithmetic mean of the experts' 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, lies at 18°C and is thus similar to the mean. The coefficient of variation of 15.55% is also indicative of a far-reaching consensus among the experts. The stated minimum equaled 12°C whereas the maximum was 22°C. Skewness is negative in this case (-0.46), which indicates a left-skewed distribution and means that most stated temperatures belonged in the upper range. A normal data distribution could not be confirmed (Shapiro-Wilk, $p < 0.05$). The histogram shown in Figure 1 provides a graphical representation of this distribution. This histogram proves a clear deviation from the normal distribution, which is represented by the solid line.

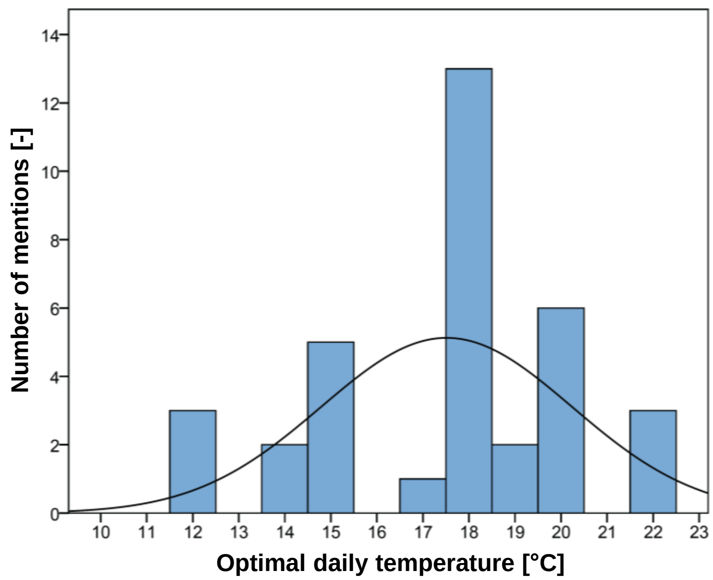

Figure 1. Optimal daily temperature histogram.

The most frequently stated temperature was 18°C (13 respondents); these mentions 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). Thus, the survey delivered a clear outcome of an optimal daily temperature of 18°C relevant to construction practice.

4 CHANGES IN DAILY TEMPERATURE – EFFECTS ON PRODUCTIVITY

The following sections of this paper deal with the influence of daily temperature on labor consumption rates and productivity.

4.1 Influence on Labor Consumption Rate

Experts were asked, in the survey, to indicate any changes in the labor consumption rate that would occur as a result of a change in daily temperature. Arithmetic means of the expert survey are shown as a trend curve in the diagram in Figure 2 (curve labelled "Daily temperature – arithmetic mean"). The optimal daily temperature is reached at 18°C; this level is associated with a labor consumption rate increase of 0%. The y-axis indicates the percentage labor consumption rate increase whereas daily temperatures are shown on the x axis. Huber's M estimator method was applied to prevent distorted results due to existing outliers and extremes. More specifically, the H12 M estimator was considered to be most useful for the purpose of this analysis. The associated curve that represents the trend in the labor consumption rate increase is labelled "Daily temperature – H12 M estimator". For daily temperatures from 6°C to about 18°C, these two curves do not differ significantly from each other. A comparison of the left and right branch of the curve reveals 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 1.5 percentage points at 0°C and rises to approx. 8.2 percentage points at -14°C. In the area right of the 18°C value, the difference between the curves is about 2.0 percentage points at 22°C and 2.3 percentage points at 38°C.

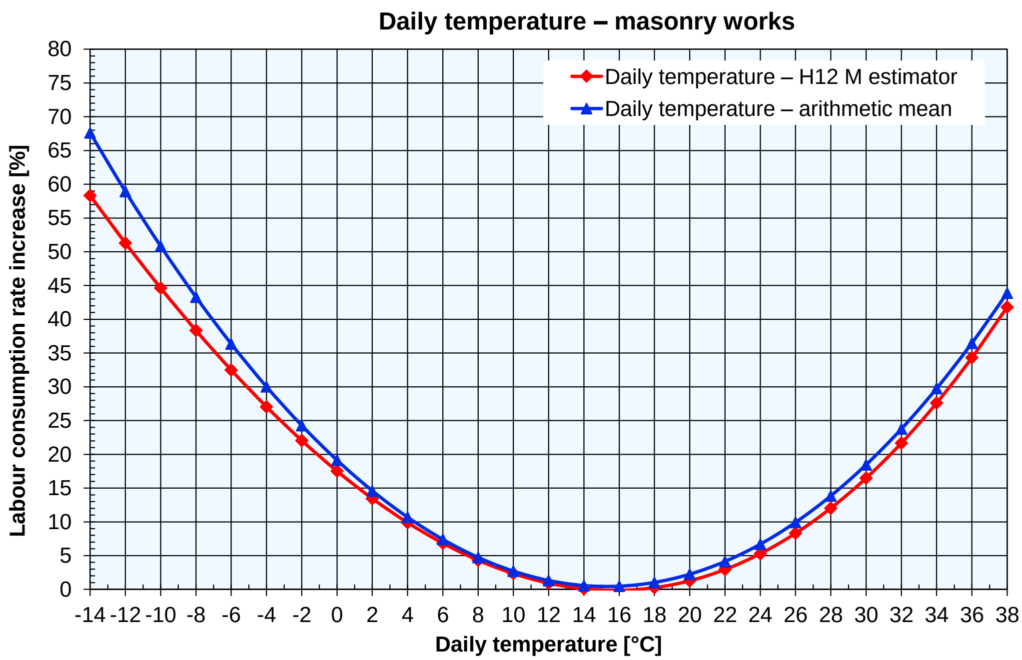

Figure 2. Diagram showing labor consumption rate increases depending on the calculation method – change in daily temperature – masonry works.

The curve determined using the M estimator method is thus recommended to show the trend in the loss of productivity because the related values are less distorted. The diagram above and the equations below can be applied to the individual project phases. The labor consumption rate derived from mean values is calculated using Eq. (1) by inserting the temperature *TMP* [°C]; it applies to the ranges of -14°C ≤ *TMP* ≤ 15°C and 18.5°C ≤ *TMP* ≤ 38°C. The range optimally suited for construction works lies between 15°C and 18.5°C.

$$\Delta LCR_{TMP,Mean} = 0.000117 \cdot TMP^3 + 0.076327 \cdot TMP^2 - 2.417692 \cdot TMP + 19.133583 \quad (1)$$

Robust mean estimators (Huber's M estimator method) were determined to prevent deletion of outliers from the survey data and to eliminate the risk of distorted results. This method assigns only a low weighting to outliers and extremes, but does consider them for the purpose of calculating mean values. It is particularly well-suited to analyzing 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).

$$\Delta LCR_{TMP,MS} = 0.000361 \cdot TMP^3 + 0.059710 \cdot TMP^2 - 2.150739 \cdot TMP + 17.511286 \quad (2)$$

4.2 Influence on Productivity

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

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

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 ≤ TMP ≤ 15°C and 18.5°C ≤ TMP ≤ 38°C.

$$\Delta PL_{TMP} = -0.000026 \cdot TMP^4 + 0.001776 \cdot TMP^3 + 0.023776 \cdot TMP^2 - 1.630319 \cdot TMP + 14.635742 \quad (4)$$

5 SUMMARY AND CONCLUSIONS

An optimal daily temperature of 18°C was determined on the basis of the outcomes of the expert survey. At this temperature, workers enjoy ideal conditions to reach 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 masonry works. Reliance on the curves determined according to the M estimator method (robust mean estimators) is recommended for practical purposes because these prevent distortion by outliers and extremes.

References

Hofstadler, C., *Produktivität im Baubetrieb – Bauablaufstörungen und Produktivitätsverluste*, Springer Vieweg, Berlin Heidelberg, 2014.

Koehn, E., and Brown, G., Climatic Effects on Construction, *Journal of Construction Engineering and Management*, American Society of Civil Engineers (ASCE), 111(2), 129-137, June 1985.

Oglesby, C. H., Parker, H. W., and Howell, G. A., *Productivity Improvement in Construction*, McGraw-Hill, New York, 1989.

Thomas, R., and Yiakoumis, I., Factor Model of Construction Productivity, *Journal of Construction Engineering and Management*, American Society of Civil Engineers (ASCE), 113(4), 623-639, December 1987.