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Forecasting labor productivity changes in construction using the PMV index

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Abstract

Over the years, many attempts have been made to establish mathematical models reflecting the relationship between the thermal environment and construction labor productivity. Once established, the models were used to forecast the change in productivity due to thermal environment variations. The models, however, failed to accurately capture the complex nature of such a relationship for a number of reasons, including a consideration of the nature of the task being performed and the effect of all known variables of the thermal environment. This paper briefly describes and highlights the main shortcomings of three established thermal environment/productivity forecasting models. It introduces a fourth model, developed by the authors, where productivity can be predicted as a function of the PMV index. The paper then presents a comparative analysis between all four models with emphasis on their sensitivity to air temperature. Field data collected from different construction sites demonstrate that observed productivity data agree well with those predicted by the PMV-based model.

Relevance to industry

To many, a construction project is considered successful if it is completed within its scheduled duration and estimated cost. Considering the various elements of cost, there would be general agreement among estimators that the element subject to most variability is the labor cost which is a function of two factors namely, unit cost of labor and labor productivity. The latter is subject to most variability due to being dependent upon many factors including thermal environment variations. Therefore, a proper evaluation of the effect of thermal environment on labor productivity is needed to estimate construction costs and schedule or to quantify damages resulting from productivity losses in construction claims.

Keywords: Construction; Thermal environment; Thermal comfort; Productivity; Mathematical models

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1. Introduction

Unlike most manufacturing industries, construction usually takes place in an open area and thus has the variation of the physical environment, including the thermal environment. Thermal environment, in the context of this paper, includes four main variables, namely air temperature, relative humidity and wind velocity, as well as mean radiant temperature (Auliciems and Szokolay, 1997). It is acknowledged that the thermal environment affects labor efficiency and may reduce their productivity (Thomas et al., 1999). However, it is still unclear how thermal environment variations impact upon productivity despite many relevant research studies that have been conducted over the last two decades (Hancher and Abd-Elkhalek, 1998). Existing knowledge about physiological and psychological effects of thermal conditions seems inadequate and does not provide construction planners or estimators with sufficient information and understanding to deal with the impact of thermal environment variations on productivity, especially during the planning stage (Mohamed and Srinavin, 2001). A comprehensive literature review of relevant research studies can be found elsewhere (Bilhaif, 1990; Srinavin, 2002).

Forecasting plays an important role in strategic and operational planning. The less analytical methods (e.g. qualitative forecasting) are frequently used for longer-ranged strategic planning and decisions making, while the more analytical methods (e.g. quantitative forecasting) are used for operational planning. Quantitative forecasting is useful in a decision process for many situations, such as in complex problems that involve many variables. The causal method is probably the most sophisticated forecasting method. It takes into account a great deal of information about the relationship between what is being forecast and a number of other variables. The most common causal method is the regression model which is a powerful method to solve prediction problems (Ferguson and Takane, 1989), and is widely used to predict labor productivity in construction (Koehn and Brown, 1985; Thomas and Yiakoumis, 1987).

Certain climatic conditions seem to have a negative effect on labor productivity. Productivity gets reduced due to the discomfort associated with noticeable thermal environment variations. For example, strong radiation from the sun causes workers to feel exhausted and seek more rest under shelter. Working in very hot weather also has physiological and psychological effects on workers; it reduces their productivity, and increases their irritability and loss of their enthusiasm for their work (Hancher and Abd-Elkhalek, 1998). In order to find a relationship between climatic conditions and productivity, a number of research studies have been conducted. In these studies, the researchers have mainly used the regression model to determine the effect of climatic conditions on productivity. This paper presents an overview of three models highlighting their shortcomings, introduces a fourth model developed by the authors and then proceeds with a comparative analysis between the four models.

2. Models description

Koehn and Brown (1985) investigated and used a wide range of published productivity data to derive two non-linear relationships relating productivity with air temperature (T_a) and relative humidity (R_h), see Eqs. (1) and (2). Eq. (1) to be used for cold or cool weather and is applicable from −29 to 10 °C. Eq. (2) to be used for warm or hot weather and is applicable from 21 to 49 °C. Using these two equations, Koehn and Brown noted that below 35% R_h, productivity is not affected by changes in humidity and argued that below −23 °C and above 43 °C, it is difficult to achieve optimum productivity.

$$P_c = 0.0144T_a - 0.00313R_h - 0.000107(T_a)^2 - 0.000029(R_h)^2 - 0.0000357(T_aR_h) + 0.647, \quad (1)$$

$$P_w = 0.0517T_a + 0.0173R_h - 0.00032(T_a)^2 - 0.0000985(R_h)^2 - 0.0000911(T_aR_h) - 1.459, \quad (2)$$