Project HeatSafe: Harnessing Machine Learning for Heat Stress Monitoring Using Environmental Data Loggers

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Introduction

The Wet-Bulb Globe Temperature (WBGT) has been recommended for assessing occupational heat stress, but its implementation in workplaces is limited, in part, by the high costs associated with accurate instruments [1]. A more practical approach involves calculating WBGT from standard environmental data (e.g., air temperature, humidity) obtained from electronic data loggers. However, this method may result in reduced accuracy owing to equipment limitations [2-3]. Recent advances in machine learning have shown promising error-correction capability, offering a potential solution for these constraints. This study aims to evaluate the accuracy of established calculation methods and machine learning algorithms in estimating WBGT from environmental measurements obtained through a cost-effective data logger.

Methods

A pair of handheld data loggers (Lascar) and a commercial-grade weather station (Vaisala) recorded ambient temperature (T_a), globe temperature (T_g) and relative humidity (RH) at 1-minute intervals over two weeks in Singapore (n=32,757 paired data). An established calculation method (CAL) was applied to Vaisala to obtain the reference WBGT (23°C−34°C), and four estimation methods were employed on Lascar: (1) CAL ($WBGT_{CAL}$), (2) Linear Regression ($WBGT_{LIN}$), (3) Polynomial Regression ($WBGT_{POL}$), and (4) Random Forest Regression ($WBGT_{RFR}$). Accuracy was assessed using Mean Bias Error (MBE), 95% Confidence Level Limits of Agreement (LOA), intraclass correlation (ICC), and percentage target attainment within ±1°C (PTA).

Results and discussion

Measurement errors were found between Lascar and Vaisala in T_g (-0.3 ± 0.7°C), T_a (0.6 ± 1.0°C), and RH (0.4 ± 2.5%) ($p<0.001$). Using these measurements to estimate WBGT, $WBGT_{CAL}$ exhibited lower accuracy and poorer agreement than all three machine learning models (Table 1). In addition, $WBGT_{POL}$ and $WBGT_{RFR}$ passed the acceptance limit for 95% PTA within ±1°C at all heat stress categories, whereas $WBGT_{LIN}$ met the criterion only at low heat stress (Figure 1).

Table 1. Performance metrics of WBGT estimation methods applied to Lascar data compared with the reference WBGT from Vaisala data.

Metrics	$WBGT_{CAL}$	$WBGT_{LIN}$	$WBGT_{POL}$	$WBGT_{RFR}$
MBE (°C)	0.26	-0.03	-0.04	-0.05
LOA (°C)	0.83	0.60	0.55	0.50
ICC	0.45	0.76	0.74	0.80
PTA (%)	73	97	98	98

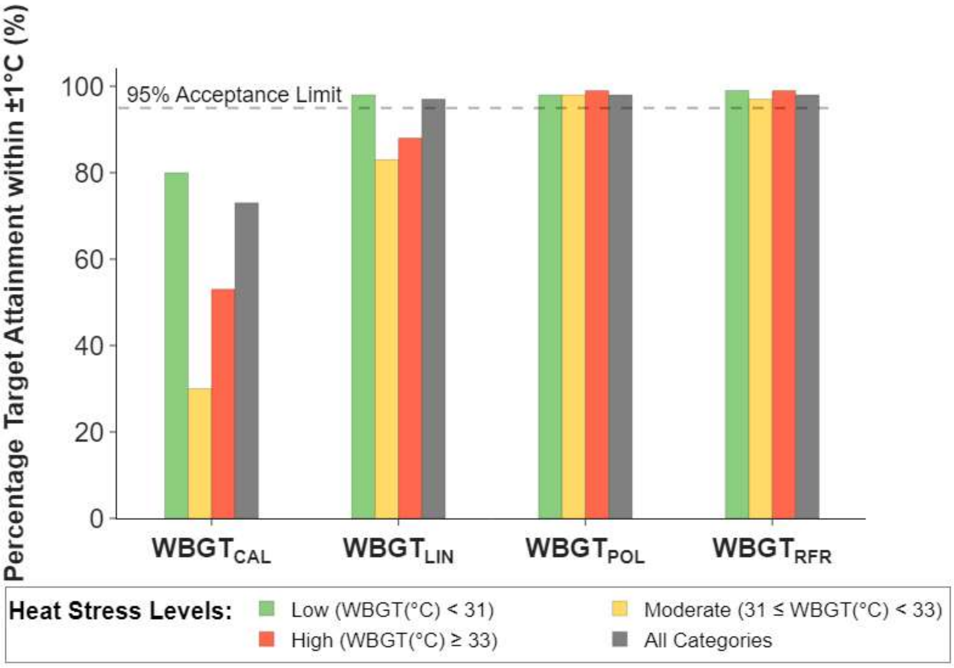

Figure 1. Percentage Target Attainment within 1°C of reference WBGT by category of heat stress levels.

Conclusions

Polynomial and random forest regression methods demonstrated high accuracy (PTA > 95%) and excellent agreement (ICC > 0.75), indicating the ability to reduce equipment measurement errors. These results showcase the potential of harnessing machine learning to enhance WBGT estimation using environmental measurements from a low-cost data logger, providing a scalable and affordable solution for monitoring workplace heat stress.

References

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