

A Machine Learning-Based Thermal Comfort Prediction Model for Older Adults

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Abstract

Indoor thermal comfort plays a critical role in safeguarding the health and quality of life of older adults (aged 60 and above), whose thermoregulatory capacity is diminished compared with younger populations due to reduced basal metabolic rate, impaired vasomotor responses, and elevated thermal sensation thresholds. While the Predicted Mean Vote (PMV) model has long served as a benchmark for thermal comfort assessment, its parameters are calibrated predominantly on young, healthy subjects and thus produce systematic prediction biases for older adults. Data-driven machine learning approaches have emerged as promising alternatives; however, existing studies that advocate deep learning architectures for thermal comfort prediction are predominantly based on small-sample datasets ($N < 500$), leaving their generalizability under large-scale data conditions unverified. This study systematically compares a Convolutional-Recurrent Neural Network (CRNN, comprising one-dimensional convolution and Gated Recurrent Unit layers) with three established machine learning algorithms—K-Nearest Neighbors (KNN), Gradient Boosting Decision Trees (GBDT), and Random Forest (RF)—using a dedicated dataset of 5 820 older adult samples constructed from the ASHRAE Global Thermal Comfort Database II. Model performance was evaluated across both regression (continuous thermal sensation prediction) and classification (discrete seven-level thermal sensation determination) tasks. Results demonstrate that RF outperformed all models: in regression, RF achieved a mean absolute error (MAE) of 0.597 3 and root mean square error (RMSE) of 0.842 7, approximately 13.1% and 15.1% lower than CRNN (MAE = 0.687 6, RMSE = 0.992 2), respectively. In classification, RF attained 78.0% accuracy and a weighted F1 score of 0.539, compared with 68.7% and 0.513 for CRNN. The CRNN exhibited pronounced overfitting and majority-class bias, attributable to an architectural incompatibility between its sequential modeling design and the non-temporal tabular nature of thermal comfort data. These findings provide evidence-based guidance for selecting models to construct individualized thermal comfort prediction systems for older adults and inform the development of intelligent age-friendly textile products.

Keywords: thermal comfort; older adults; machine learning; convolutional-recurrent neural network; random forest; prediction model

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1 Introduction

With the irreversible progression of global population aging, designing indoor living environments that balance health and comfort for older adults has become a critical interdisciplinary issue spanning environmental engineering and public health. Physiological research confirms that compared with younger populations, the thermoregulatory systems of older adults exhibit significant degenerative characteristics, primarily manifested as reduced basal metabolic rate, sluggish vasomotor responses, and pathological elevation of thermal sensation thresholds [1-3]. Specifically, older adults experience diminished peripheral vasoconstriction and vasodilation efficiency, leading to impaired heat dissipation and retention capacity; reduced metabolic heat production renders them more vulnerable to cold stress; and attenuated sweat gland function limits evaporative cooling under warm conditions [3, 4]. These age-related physiological declines substantially weaken older adults' adaptive capacity to adjust to fluctuations in the indoor thermal environment. They can readily trigger cascading health risks, including increased cardiovascular workload, respiratory infections, and sleep disorders [1, 5]. Consequently, indoor thermal comfort assessment for older adults requires methodologies that account for these population-specific physiological characteristics, rather than relying on models calibrated for younger, healthier populations.

For an extended period, indoor thermal comfort assessment has primarily relied on the Predicted Mean Vote (PMV) model proposed by Fanger [6]; however, this model exhibits significant theoretical deficiencies in its applicability to older adults. The PMV model is built on idealized assumptions of “human thermal balance” and a “steady-state environment”, with its parameters predominantly calibrated from experimental data on young, healthy populations, failing to account for individual differences arising from aging, such as metabolic rate decline and diminished thermoregulatory capacity [7, 8]. Empirical studies demonstrate that direct application of the PMV model to older populations typically produces systematic prediction biases, often manifested as misjudgment of thermal sensitivity in older adults [9, 10]. This “misalignment” between physical models and human perception renders existing environmental regulation strategies inadequate to meet the thermal requirements of older adults.

Data-driven approaches represented by machine learning have gradually emerged as research hotspots due to their powerful nonlinear mapping capabilities. Early studies using traditional algorithms such as support vector machines and decision trees outperformed the PMV model in predictive accuracy [11]. In recent years, complex deep learning architectures have been introduced to this field, with some small-sample studies claiming their performance superiority over traditional models [12, 13]. Nevertheless, this conclusion lacks rigorous validation of generalization. First, deep models designed for image or time-series data may be structurally incompatible with typical thermal comfort datasets, which typically consist of discrete, non-temporal tabular data. Second, existing studies are mostly based on small sample sizes ($N < 500$); under limited data scales, complex deep models are highly susceptible to overfitting, making their advantages in specific experiments difficult to replicate in practical engineering.

Meanwhile, the thermal comfort of clothing systems represents another critical dimension of the human thermal environment that directly influences model input parameters. Research has demonstrated that fabric properties significantly affect clothing thermal comfort performance under varying environmental temperatures [14], and clothing system design—including fabric structure, air permeability, and moisture transfer characteristics—plays a decisive role in the microclimate between the skin and the external environment [15, 16]. Furthermore, studies on heat and moisture transfer in human–clothing–environment systems have established that clothing