Optimizing supervised learning model for thermal comfort and air quality

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ABSTRACT

Thermal comfort and indoor air quality are essential factors that directly influence occupants' health and activity efficiency. Ensuring optimal thermal conditions also supports energy-efficient buildings by preventing energy waste. Machine learning models have been extensively applied to classify thermal comfort and air quality, with supervised learning algorithms such as support vector machine (SVM) and K-nearest neighbor (KNN) showing high accuracy. However, no prior study has compared or combined these two models for simultaneous prediction of thermal comfort and air quality, especially in diverse geographical settings. This study aims to develop and compare SVM and KNN to determine the most accurate model for enhancing thermal comfort and air quality in highland and lowland Islamic boarding schools. Using a quantitative approach, we collected datasets from schools in Wonosobo (highland) and Pontianak (lowland). The results show that KNN outperforms SVM in accuracy, precision, and F1-score. Additionally, a hybrid model integrating both algorithms further improves accuracy, achieving 91%. These findings highlight the effectiveness of machine learning in optimizing environmental conditions in educational settings.

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1. INTRODUCTION

Climate change harms human life. One of the impacts is global warming in urban areas known as the Urban Heat Island (UHI) [1]. Hot areas will expose buildings to hot air. The air quality inside buildings becomes bad. Therefore, strategies are needed to create good air quality inside buildings [2].

The quality of air is crucial for the health of the Islamic boarding school residents. Optimal air quality positively influences health, whereas subpar air quality adversely affects well-being and induces discomfort among residents indoors [3], [4]. Indoor air quality is closely related to thermal comfort variables. Poor air humidity is one of the thermal variables that causes poor air quality, causing health problems [5]. Poor air quality will also cause a decrease in human performance at work [6]. Indoor air quality is related to building ventilation. Natural ventilation is one way to maintain good air quality [7]. Natural ventilation is considered a simple and effective method of air exchange. Occupants have a major influence on the effectiveness of natural ventilation [8]. Natural ventilation design strategies are one way to create energy efficiency [9]. Air speed through ventilation is one aspect that influences the thermal comfort variable. The air mass flow rate has quite a large impact compared to the increase in air temperature [10]. Energy efficiency can be achieved by using renewable alternative energy such as solar cells [11]. Energy efficiency in buildings depends on the behavior of occupants in responding to environmental conditions [12]. In the realm of architectural science, thermal comfort, energy-saving characteristics, passive solar architectural elements, and construction techniques need to be analyzed to find energy-efficient buildings [13]. The residents' comfort is also affected by thermal comfort or the air temperature within the Islamic boarding school. Air quality and ventilation are crucial for establishing thermal comfort within the environment of an Islamic boarding school (Islamic boarding school). Thermal comfort can enhance the efficacy of residents' indoor activities. Moreover, thermal comfort can facilitate the construction of energy-efficient edifices, thereby mitigating energy waste [14], [15]. Energy inefficiency frequently transpires in environments where air quality and thermal comfort are suboptimal [16].

The distinct natural conditions of highlands and lowlands can influence air quality and thermal comfort. Highlands typically exhibit lower temperatures and reduced air density, whereas lowlands generally experience elevated temperatures and increased humidity [17]. To enhance air quality and thermal comfort in Islamic boarding schools situated in highland and lowland regions, a supervised learning model may be employed [18]. Supervised learning is a machine learning technique utilized to analyze data and predict air quality and thermal comfort in Islamic boarding schools [19], [20]. Algorithms encompassed within the supervised learning paradigm include support vector machine (SVM), K-nearest neighbor (KNN), among others [21], [22].

Table 1 reveals that studies have been undertaken to predict thermal comfort and air quality utilizing machine learning models with diverse supervised learning algorithms. Nonetheless, no previous research has integrated thermal comfort with air quality forecasting. Moreover, numerous studies have identified algorithms with optimal accuracy, such as SVM and KNN. This research integrates these two algorithms to create an optimal hybrid model for predicting thermal comfort and air quality.

Table 1. Literature review

Author number	Reviewing results
[4]	This research formulates a prediction model for indoor PM10 concentrations using multiple linear regression analyses, focusing on elementary schools, kindergartens, and daycare centers in Seoul, South Korea. The findings indicate that daycare centers exhibit the highest concentrations.
[23]	This research examines indoor air quality studies across various countries, utilizing variables such as volatile organic compounds (VOCs), particulate matter (PM), and carbon dioxide (CO_2). The results show that increasing airflow can reduce alarmingly elevated pollutant concentrations.
[24]	This research employs the SVM algorithm in machine learning to predict pollutant levels, particulate metter, and the air quality index. The classification utilized six air quality categories, attaining an accuracy of 94.1%.
[25]	This research presents an energy-efficient thermal comfort model utilizing a machine learning methodology. The simulation results indicate that the SVM algorithm surpasses other algorithms.
[26]	This study seeks to forecast thermal comfort utilizing data through the SVM algorithm and various other machine learning algorithms. In comparison to other algorithms, the results show that SVM makes thermal comfort predictions much more accurate.
[27]	This study constructed a thermal comfort model utilizing the KNN method to establish adaptive comfort for passengers. We evaluated the KNN-based thermal comfort model using 1,000 datasets and achieved a relatively high accuracy level.
[28]	This research aims to forecast the air quality index utilizing ANN and KNN algorithms. The conclusion indicates that the KNN algorithm attained the highest accuracy.
[29]	This research introduces a thermal comfort monitoring system for hot and humid climates utilizing the KNN model. The findings indicate that the model attains a satisfactory accuracy score.

2. METHOD

This research employs a quantitative methodology, commencing with the delineation of research problems and objectives, which has been finalized, succeeded by a literature review of antecedent studies pertinent to the subject matter. Data collection surveys and permissions will be executed at 5–10 Islamic boarding schools in both highland and lowland regions, with Wonosobo, Central Java, exemplifying the highlands and Pontianak, West Kalimantan, exemplifying the lowlands. The data collection in Wonosobo will encompass thermal comfort variables, including air temperature, humidity, wind speed, solar radiation temperature, activity, and clothing, measured with instruments such as humidity meters, solar radiation sensors, and anemometers. Additionally, air quality variables, specifically CO_2, PM10, PM2.5, and PM1.0, will be assessed using CO_2 sensors and particle counters. Comparable data will be gathered in Pontianak utilizing the same instruments. A minimum of 2,000 datasets will be gathered from each location, yielding a total of 4,000 datasets. Following data collection, a recap and preparation of the data will be executed for the development of supervised learning models utilizing the SVM and KNN algorithms, implemented in Python and Google Colab. A hybrid model integrating these algorithms will be developed and optimized to attain optimal predictions for air quality and thermal comfort.

Thermal comfort and air quality in Islamic boarding schools located in highland and lowland areas need optimization. Data collection will involve measuring thermal comfort and indoor air quality variables. Research data will be collected from several Islamic boarding schools in Wonosobo, representing highland areas, and Pontianak, representing lowland areas, with 2,000 datasets each, resulting in a total of 4,000 datasets. Previous studies have shown that machine learning approaches can predict outcomes based on data patterns [18]. Machine learning models can also forecast thermal comfort and air quality [17]. Some studies have demonstrated that supervised learning algorithms, such as SVM and KNN, achieve high accuracy levels [29]. However, these two algorithms have not yet been used together to predict both air quality and thermal comfort.

The objective of this research is to develop a hybrid supervised machine learning model using the SVM and KNN algorithms. By combining these two algorithms, an optimal model is expected to predict air quality and thermal comfort.

3. RESULTS AND DISCUSSION

3.1. Research data descriptions

Islamic boarding schools were situated in two separate locations: Wonosobo, denoting highland areas, and Pontianak, denoting lowland areas. A cumulative total of 4,000 datasets was amassed, comprising 2,000 datasets from each site. The assessed variables encompassed air temperature, humidity, wind velocity, and solar radiation for thermal comfort, in addition to CO_2, PM10, PM2.5, and PM1.0 concentrations for air quality.

The datasets were examined employing supervised learning models to forecast air quality and thermal comfort. Classification was conducted according to the ecological attributes of the two areas. Highland regions typically demonstrated reduced temperatures and humidity relative to lowland regions, which usually experienced elevated temperatures and humidity levels.

3.1.1. Temperature distribution

Measurements indicated that air temperatures in Wonosobo had a lower distribution, averaging approximately 25 °C, whereas Pontianak displayed higher temperatures, averaging around 31 °C. This illustrates the climatic disparities between highland and lowland regions, with lowlands typically exhibiting warmer temperatures. Figure 1 depicts the air temperature distribution in both locations.

3.1.2. The air humidity distributions

The air humidity differs from the two research sites. Wonosobo had lower humidity than Pontianak. Figure 2 shows the air humidity distribution graphics of both locations.

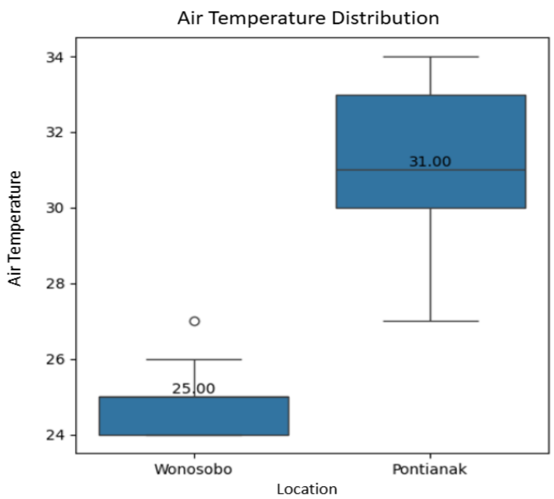

Figure 1. The air temperature distributions in Wonosobo and Pontianak

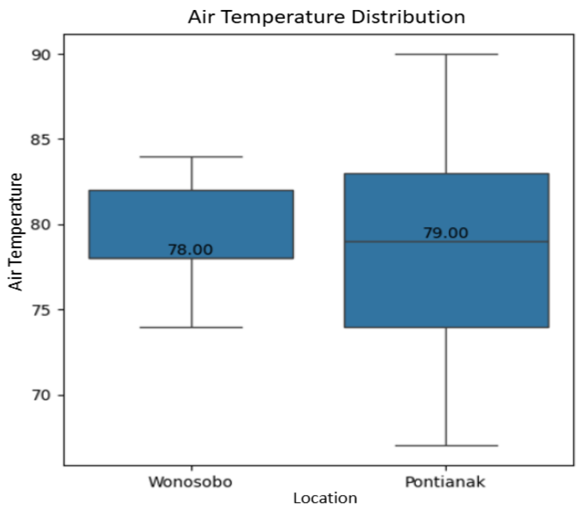

Figure 2. The air humidity distributions in Wonosobo and Pontianak

3.1.3. The distribution of CO2

The CO_2 concentration measurement is useful to assess the air quality at the Islamic boarding schools. The results show the CO_2 concentration in Wonosobo is higher than Pontianak. Figure 3 visualizes the CO_2 concentration distributions from both locations.

3.1.4. The distribution of PM2.5

The measured PM2.5 particle concentrations indicated that Wonosobo experienced higher air pollution levels compared to Pontianak. Wonosobo had an average PM2.5 concentration of 25 µg/m³, while Pontianak had a lower average of about 15 µg/m³. Figure 4 illustrates the PM2.5 distribution across the two locations.

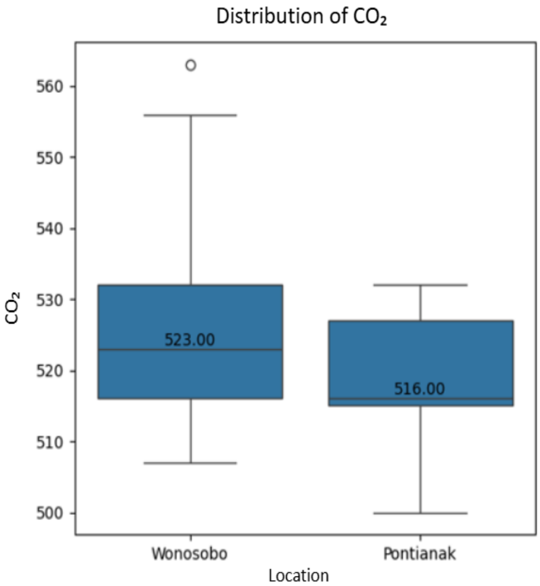

Figure 3. CO_2 distributions in Wonosobo and Pontianak

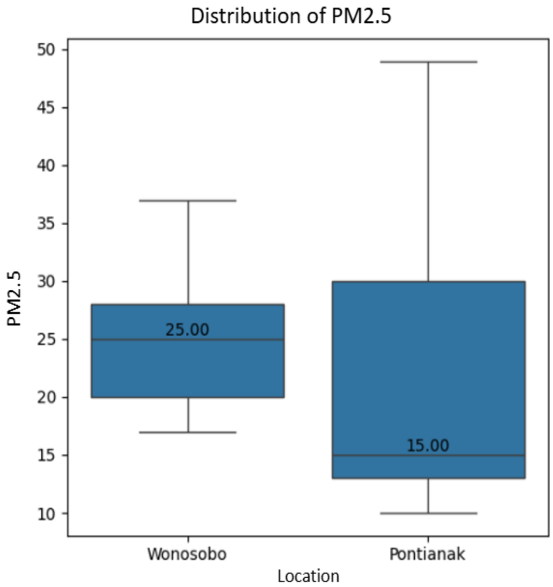

Figure 4. The PM 2.5 distributions in Wonosobo and Pontianak

3.2. SVM algorithm evaluation

In this study, the SVM algorithm is applied to predicts the air quality and temperature comfort in Islamic boarding schools in both highland and lowland areas. The model's performance using key evaluation metrics such as recall, accuracy, and F1-score. A confusion matrix was used to show the predictions.

The SVM model was trained on weather-related data collected from the boarding schools, including air temperature, humidity, CO_2 concentration, and levels of PM2.5, PM10, and PM1.0. The thermal sensation vote (TSV), which is a list of types of thermal comfort, was the variable that was being looked at. The tests showed that the SVM model could predict both air quality and thermal comfort.

Figure 5 shows that the SVM model results was right 77% of the time, which means it was pretty good at figuring out thermal comfort levels based on air quality. But a precision of 46% means that only 46% of positive predictions were right, which means that there were a lot of false positives. A recall of 54% means that the model was able to find more than half of the positive cases, though some were missed. The 47% F1-score shows a moderate balance between accuracy and recall, showing that the model's performance needs more work to get better results.

To get a better idea about the excellence of the model, the prediction results were shown using a confusion matrix, which you can see in Figure 6. This shows how many correct and incorrect predictions the SVM model made.

The evaluation shows the SMV model has excellent performance in predicting the air quality and thermal comfort. The accuracy is 77%, indicating the capability to differ the thermal comfort in each category.

	precision	recall	f1-score	support
Cold	0.04	0.33	0.06	3
Cool	0.00	0.00	0.00	65
Slightly Cool	0.00	0.00	0.00	1
Neutral	0.57	0.97	0.72	134
Slightly Warm	0.86	0.91	0.88	156
Warm	0.94	0.78	0.86	367
Hot	0.79	0.79	0.79	67
accuracy			0.77	793
macro avg	0.46	0.54	0.47	793
weighted avg	0.77	0.77	0.76	793

Figure 5. The SVM model evaluation

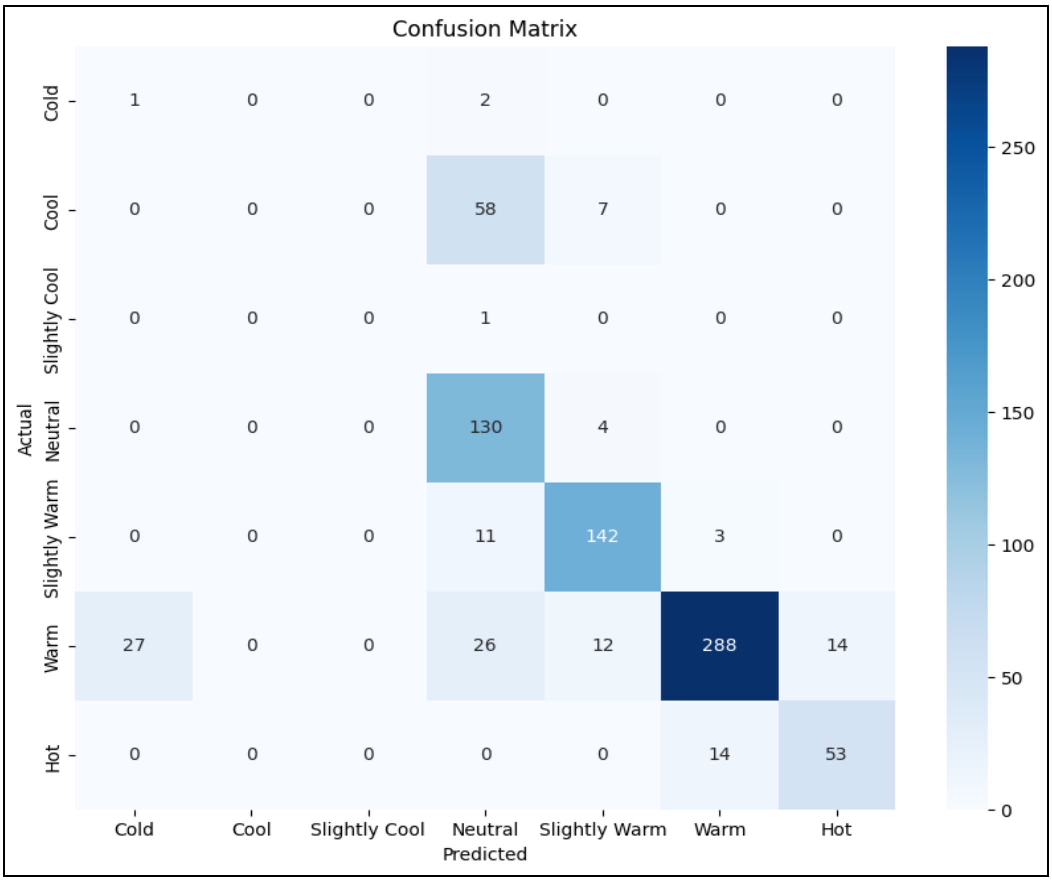

Figure 6. Confusion matrix model SVM

3.3. KNN algorithm evaluation

The KNN algorithm predicted the thermal comfort and air quality within Islamic boarding schools. The evaluation aimed to measure the model's effectiveness in predicting thermal comfort conditions using environmental variables such as air temperature, humidity, CO_2 concentration, and particulate matter levels (PM2.5, PM10, and PM1.0).

To evaluate the KNN model's performance in predicting thermal comfort and air quality, various metrics such as accuracy, precision, recall, and F1-score were applied. In Figure 7, the KNN model achieved an accuracy of 88%, indicating its ability to correctly predict a significant portion of the data. The precision of 50% implies that half of the positive predictions made by the model were accurate. With a recall of 54%, the model successfully identified over half of the positive cases, although some were missed. The F1-score of 52% highlights a moderate balance between precision and recall, showcasing consistent prediction performance, albeit with room for improvement. Figure 8 provides a confusion matrix illustrating the distribution of correct and incorrect predictions made by the KNN model for each class. From the evaluation results, the KNN model demonstrated excellent performance in predicting air quality and thermal comfort, although it slightly underperforms compared to the SVM model.

	precision	recall	f1-score	support
Cold	0.00	0.00	0.00	3
Cool	0.00	0.00	0.00	65
Slightly Cool	0.00	0.00	0.00	1
Neutral	0.67	0.84	0.74	134
Slightly Warm	0.85	0.98	0.91	156
Warm	0.96	1.00	0.98	367
Hot	1.00	0.94	0.97	67
accuracy			0.88	793
macro avg	0.50	0.54	0.52	793
weighted avg	0.81	0.88	0.84	793

Figure 7. KNN model evaluation

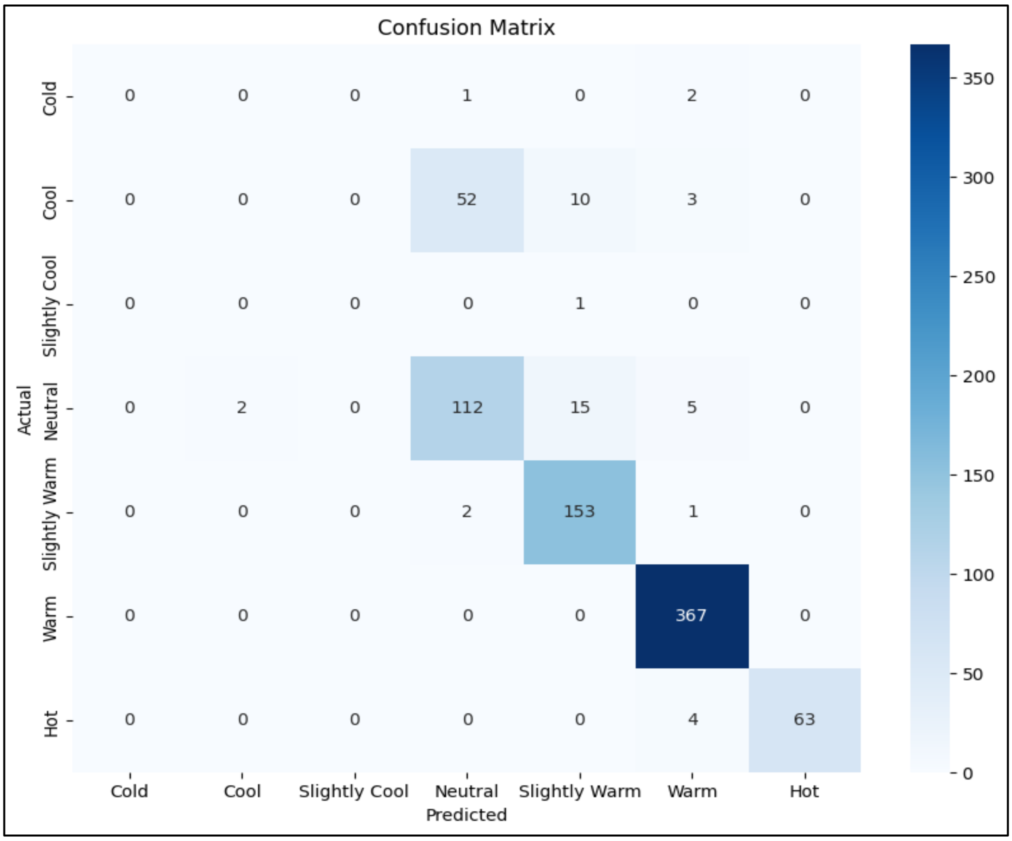

Figure 8. Confusion matrix model KNN

3.4. SVM-KNN comparative analysis

This study implemented both the SVM and KNN algorithms to predict thermal comfort and air quality in Islamic boarding schools. The two models were evaluated separately to determine their strengths in predicting thermal comfort based on environmental features such as humidity, air temperature, wind speed, CO_2, PM2.5, PM10, and PM1.0.

Evaluation metrics such as accuracy, precision, recall, and F1-score were utilized to compare the effectiveness of the two algorithms. A detailed comparison of the results for both models is summarized in Table 2. Table 2 shows the KNN model outperformed the SVM model with an accuracy of 88%, compared to SVM's accuracy of 77%. This indicates that KNN is slightly more reliable in predicting overall thermal comfort. KNN achieved a precision of 50%, marginally better than SVM's precision of 46%, suggesting that KNN is somewhat more accurate in predicting thermal comfort. Both models had an identical recall score of 54%, reflecting their ability to detect more than half of the positive cases. The F1-score for KNN was 52%, outperforming SVM's score of 47%, signifying that KNN offers a better balance between precision and recall.

Table 2. SVM-KNN model performance comparison

Algorithm	Accuracy	Precision	Recall	F1-score
SVM	77	46	54	47
KNN	88	50	54	52

To provide a clearer comparison of the performance between the SVM and KNN models in predicting air quality and thermal comfort in Islamic boarding schools, a visual representation of their performance comparison is shown in Figure 9. Figure 9 illustrates that KNN performs better than SVM in predicting air quality and thermal comfort in Islamic boarding schools, based on higher accuracy, precision, and F1-score.

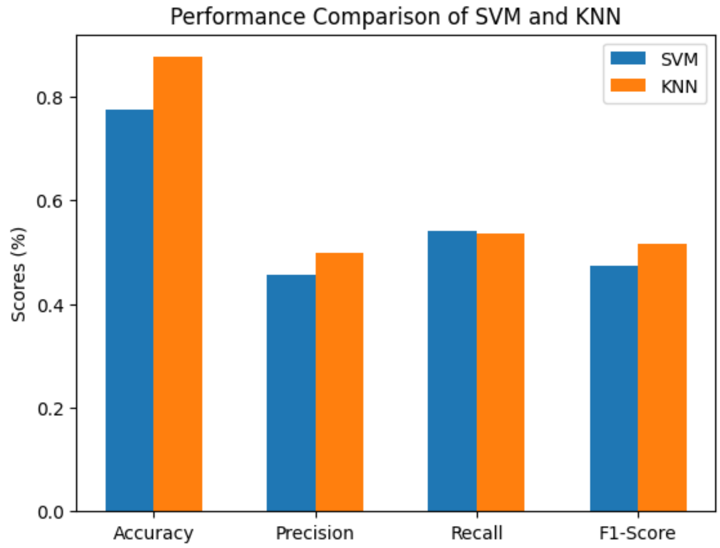

Figure 9. SVM-KNN performance comparison

3.5. The hybrid SVM-KNN model development

A hybrid model using SVM and KNN algorithms was created to improve air quality and thermal comfort predictions. This hybrid model uses each algorithm's strengths to make better predictions. SVM is used in many classification tasks because it can classify data with clear margins, while KNN is good at responding to local data patterns. Voting classifiers were used to combine these strengths and make a final prediction by voting from both algorithms. Soft voting averages the prediction probabilities from SVM and KNN, allowing each model to contribute proportionally to the final prediction based on confidence levels.

The hybrid model was developed methodically. The dataset was utilized to train the SVM model for predicting thermal comfort based on environmental variables. Parallelly training the KNN model with the same dataset followed. Finally, the soft voting mechanism combined SVM and KNN probabilistic predictions to produce the final result. Figure 10 shows the hybrid model's performance evaluation after development.

The SMV-KNN comparision of the hybrid model performance used primary evaluation matrices including accuracy, precision, recall, and F1-score. Table 3 shows the hybrid model performance comparison from individual model. The hybrid model showed an improvement in accuracy, reaching 91%, which is higher than the individual SVM and KNN models. This indicates that by combining the strengths of both algorithms, the hybrid model is able to overcome the weaknesses of each individual algorithm. The hybrid model also exhibited a higher precision of 64%, compared to both SVM and KNN. This indicates that the hybrid model provides grather accuracy in predicting thermal comfort. The recall of the hybrid model increased to 58%, higher than that of SVM and KNN, showing that the hybrid model is better at capturing all classes of thermal comfort. Achieving an F1-score of 56%, the hybrid model demonstrated a more balanced performance between precision and recall than the individual models.

	precision	recall	f1-score	support
Cold	0.00	0.00	0.00	3
Cool	0.86	0.09	0.17	65
Slightly Cool	0.00	0.00	0.00	1
Neutral	0.69	0.96	0.80	134
Slightly Warm	1.00	0.99	1.00	156
Warm	0.97	1.00	0.98	367
Hot	1.00	0.99	0.99	67
accuracy			0.91	793
macro avg	0.64	0.58	0.56	793
weighted avg	0.92	0.91	0.88	793

Figure 10. Hybrid model evaluation

Table 3. The hybrid model performance comparision from the individual model

Algorithm	Accuracy	Precision	Recall	F1-score
SVM	77	46	54	47
KNN	88	50	54	52
Hybrid	91	64	58	56

Figure 11 displays a graph showing the comparison of model performance to visualize the performance of the hybrid model and compare it with the individual models. Figure 11 presents a comparison of the accuracy, precision, recall, and F1-score among the SVM, KNN, and hybrid models, clearly showing that the hybrid model surpasses both individual models accross all evaluation metrics.

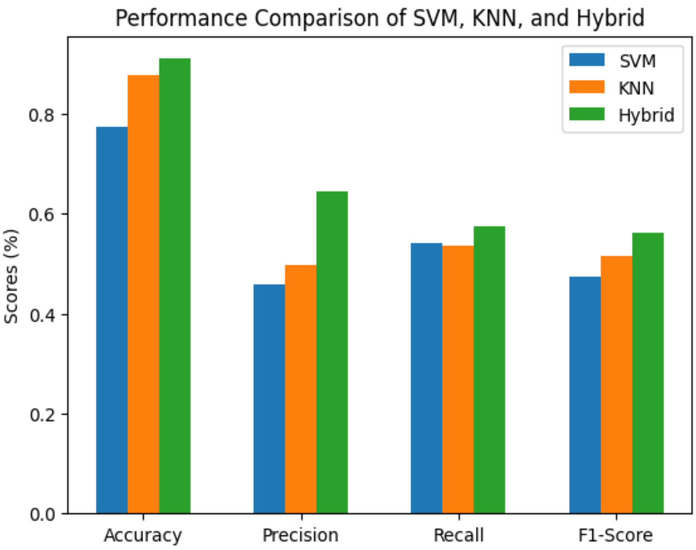

Figure 11. The graphics of hybrid model performance comparison from indiviual model

The evaluation results indicate that the hybrid SVM and KNN model provides a significant performance improvement compared to the individual models. This hybrid model excels at handling air quality and thermal comfort predictions in diverse environmental conditions, both in highland and lowland areas. The success of this hybrid model underscores the potential of combining two different algorithms to achieve more accurate and balanced predictions, enhancing the model's reliability in predicting thermal comfort conditions.

3.6. Discussion

This study demonstrates that supervised learning algorithms, particularly KNN and SVM, can predict air quality and thermal comfort in Islamic boarding schools across different geographical conditions. The results show that KNN outperforms SVM with an accuracy of 88% compared to 77%, highlighting its strength in detecting local patterns, whereas SVM excels in classification with clear margins [30]. Environmental differences influenced predictions, with Wonosobo (highland) experiencing lower temperatures but higher CO_2 and PM2.5 levels, while Pontianak (lowland) had better air quality but higher temperatures. The integration of KNN and SVM through a hybrid model achieved the highest accuracy of 91%, demonstrating the effectiveness of combining algorithm strengths for improved predictive performance. This model provides an effective solution for enhancing air quality, thermal comfort, and energy efficiency across different settings.

The results of this study are consistent with previous research emphasizing the effectiveness of machine learning in predicting thermal comfort and air quality. Prior studies have demonstrated that ensemble models and hybrid approaches can improve prediction accuracy [31], [32]. The superior performance of the KNN-SVM hybrid model in this study (91% accuracy) is consistent with the results of previous work, where ensemble techniques enhanced model performance from 40% to 60% [31]. Additionally, research on occupant prediction using different machine learning models has shown varying accuracy levels, with CNN achieving 97.3% and RF reaching 89.3% [33], further supporting the notion that model selection significantly impacts predictive accuracy. Compared to studies that focused on energy-saving prediction using deep learning approaches such as DNN (96% accuracy) [34] and automated machine learning models with multi-objective optimization (95% accuracy) [35], this study introduces a hybrid approach that leverages both local pattern detection KNN and clear-margin classification SVM to achieve a competitive accuracy level. Moreover, this study provides new insights by specifically analyzing Islamic boarding schools in different geographical conditions, which has not been explicitly explored in previous research.

Although this study has demonstrated the effectiveness of the hybrid KNN-SVM model in predicting air quality and thermal comfort in Islamic boarding schools, future research could investigate additional approaches to further improve predictive performance and expand its range of applications. Future research can explore deep learning models like CNN or RNN to enhance predictive accuracy. Expanding the dataset across diverse climates will improve model generalizability. Integrating real-time IoT sensor data could enable dynamic air quality and energy optimization. Additionally, investigating the socio-economic impacts of predictive models on energy efficiency and student well-being would provide a more comprehensive perspective on sustainable management of Islamic boarding schools.

This study demonstrates the effectiveness of machine learning in predicting thermal comfort and air quality in Islamic boarding schools. The hybrid KNN-SVM model achieved the highest accuracy, offering a practical approach to optimizing environmental conditions. These findings lay the groundwork for future research on adaptive models to enhance air quality, energy efficiency, and student well-being.

4. CONCLUSION

This research highlights the significance of predictive models in optimizing thermal comfort, air quality, and energy efficiency in Islamic boarding schools with diverse geographical conditions. A comparison between SVM and KNN reveals that KNN surpasses SVM in terms of accuracy, precision, recall, and F1-score. The integration of both models into a hybrid approach further enhances predictive accuracy, offering a balanced solution. These findings emphasize the potential of machine learning in sustainable energy management, encouraging further research to refine predictive models, incorporate real-time environmental factors, and explore broader applications in similar settings.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration

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Hermawan		✓				✓		✓	✓	✓	✓	✓		
Ely Nurhidayati	✓		✓	✓		✓			✓		✓		✓	

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [HS], upon reasonable request.

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